Improving and Optimizing Operations: Things That Actually Work!

Plant Operators' Forum 2004

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Contents

Preface

Periodically, the Minerals and Metallurgical Processing Division of SME puts together a Plant Operators' Forum at the annual meeting. Over the years, the attendees have found these forums to be quite valuable, and their popularity has steadily increased.

After a number of difficult years for the minerals industry, it seems apparent that the industry could now be poised for growth and expansion. Although welcomed, this expansion will present a new set of challenges to the business. By focusing on solving real-life problems, presented in real-life terms, this Plant Operators' Forum addresses some of the most challenging topics and issues that mining companies face. Because the program was developed to benefit the SME operators, we go beyond our own industry jargon and explore topics such as "How the Mine Department Lies About Production and How the Metallurgist Catches Them," "Does the Right Hand Know That the Left Hand is Mining?" and "How to Sell R&D in Your Organization—Without Begging." The overall program was designed to tackle three major areas of focus—People, Processes, and Technology.

The contributors to this work represent a Who's Who list of international mining professionals. As operators ourselves, we know that it's difficult to find the time to develop and prepare a professional paper, so we greatly appreciate the time and effort expended by the contributing authors to this work. We would also like to thank the session chairs and the SME staff for their support of this forum.

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Cleveland-Cliffs, Inc.

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The Art of Mining to Processing Reconciliation

or

How the Mine Department Lies About Production and How the Metallurgist Catches Them

Control of Blasting for Ore Blending and Autogenous Mill Performance at Hibbing Taconite Company—Preliminary Findings

Peter R. VanDelinder,* Jack W. Eloranta,† and Michael J.T. Orobona*

Ore blending for process optimization is becoming an increasing factor for managing cost and productivity. Economic mining and processing a very low value ore in an extremely competitive market results in constant cost-cutting initiatives. The inherent conflict between the lowest possible mining cost and the lowest possible milling cost is reviewed here in the context of blasting for autogenous mills.

Iron ore blending focuses on a number of properties—liberation values, weight recovery and concentrate silica being the most important. Other chemical and metallurgical factors are also commonly controlled. Recent research has fueled an emerging interest in blending on physical ore properties as well.

Fully autogenous mills rely on the large, competent fraction of crushed feed to act as grinding media. Previous test work indicated that Hibtac mills require specific amounts of 6- to 10-inch ore. High recirculating loads require a steady influx of large rock fragments. Blast designs, therefore, are presently characterized by wide patterns and low powder factors. Current efforts are aimed at improving mill throughput while reducing overall energy costs.

Based on research and published case studies and the advent of optical measuring devices, Hibbing Taconite Company has embarked on a blast optimization program to identify optimum mill feed and to design blast fragmentation goals for each geological unit and each mining area.

This paper outlines the preliminary findings of an ongoing, broad-based team effort which requires close cooperation of geologists, mine engineers, crushing and milling personnel. Three specific areas of investigation are reviewed: 1) Historical relationships between powder factor and mill performance, 2) Blast fragmentation modeling using the Kuz-Ram model, and 3) Drill

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core measurements relating bed thickness to mill performance. Early findings suggest that in-situ bed thickness has an effect on mill throughput. A second finding is that even high powder factor blasts still produce a large amount of the coarse feed needed for the autogenous mills.

INTRODUCTION

Hibbing Taconite Company

Hibbing Taconite Company (Hibtac) is located on the Western Mesabi Iron Range near the town of Hibbing in northern Minnesota. It is owned 62.3% by International Steel Group, 14.7 % by Stelco Inc. and 23% by Cliffs Mining Company, which is also the managing agent.

At a rated capacity of 8.1 million tons of iron pellets annually, Hibtac mines an average of 30 million tons of taconite ore and 50 million tons all material, annually.

The Hibtac processing flowsheet consists of two 60" gyratory crushers, nine 36-ft-diameter autogenous grinding mills, two stages of magnetic separation, four balling drums per indurating line and three traveling grate pelletizing machines. Hibtac began pellet production during the third quarter of 1976 and made its initial shipment to the port of Superior, Wisconsin, in January of 1977.

GEOLOGY

A previous description of Hibbing mine geology was compiled by Djerlev (1993). Hibtac's reserve is in the Lower Cherty Member of the Biwabik Iron Formation, a tabular chemical sedimentary deposit dipping gently to the southeast. Taconite denotes the bedded or wavy-banded, massive to laminated ferruginous rock found in the greater Lake Superior iron-mining district. Principal minerals in taconite typically include quartz, chert, magnetite, and minnesotaite with lesser amounts of goethite, siderite, ankerite, and greenalite (Gruner 1946; White 1954). Minor amounts of stilpnomelane and hematite also occur at Hibtac (Djerlev 1993). Taconite varies from slightly to highly magnetic; magnetite occurs as disseminated individual octahedra, aggregates of octahedra, and layered clusters formed by interconnecting aggregates of grains (Morey 1993). Two different types of iron formation are distinguished in the Biwabik Formation (Gruner 1946; White 1954; French 1968). *Cherty* taconite is massive and quartz-rich, and characteristically has a granular texture due to the occurrence of iron silicates in rounded or irregular, 0.5 to 2.0 mm granules. *Slaty* taconite is generally dark, fine-grained and finely laminated; it is composed mainly of iron silicates and carbonates, argillite, and carbonaceous matter.

The taconite mined at Hibtac averages 18.7% crude magnetic iron. Five local subunits of the Lower Cherty Member comprise the orebody. Ore units are ascribed the nomenclature "slaty" or "cherty" based on the relative proportions of the two material types. The higher-grade ore consists of the 1-6 and 1-5 cherty taconite subunits, with a thickness of roughly 100 feet. These are overlain by the 1-7 lean cherty taconite subunit, which is approximately 20 feet thick. The cherty subunits consist of 2- to 12-inch-thick massive silicate chert zones with disseminated magnetite separated by 1/10th- to 2-inch-thick, slaty argillite-magnetite bands (Djerlev 1993). Beneath the 1-5/6 zone is lean slaty taconite of the 1-4 and 1-3 subunits totaling 30 feet in thickness. This interval consists of interbedded argillite, magnetite and minor hematite forming laminated

bands from 2 to 10 inches in thickness separated by 2- to 4-inch-thick massive cherty zones (Djerlev 1993). Total mineable stratigraphic thickness of the Hibbing orebody is approximately 150 feet.

Physical Ore Specifications

Mine engineers and plant metallurgists recognize the importance of close control of feed to the plant. Every operation has developed key parameters on which the daily blend is based. Mesabi Range iron ore is no exception. Weight recovery, liberation values, silica and ferric/ferrous iron ratios must be controlled as well as slaty versus cherty rock type percentages.

Hibtac has a long history of also specifying a maximum powder factor (lbs of powder per long ton of rock) used in blast design. Fully autogenous (AG) mills require feed that includes a percentage of coarse sizes. Early research pointed to an optimum feed of 40% minus 3-inch, 20% 3- to 6-inch and 40% 6- to 10-inch rock. Actual blasted and crushed feed exhibits a spectrum of size fractions reflecting rock properties, blast design and crusher setting. Revisiting these size specifications may be helpful given the recent advances in computer modeling and in fragment size measurement. Two obvious questions include What is the best feed for the AG mills, and What blast designs are required to economically produce such feed?

Today, Mesabi Range iron ore producers are challenged, as never before, to reduce costs or face closure. Higher-grade deposits were depleted during the past century of mining. Worldwide competition from high-grade producers is intense. Exacerbating the situation is the rising cost of energy. Flint-hard taconite must be ground to 75% minus 325 mesh in order to liberate magnetite from the gangue. Concentrate is subsequently pelletized in another energy-intensive process to facilitate shipping and blast furnace productivity.

In response to this challenge, Hibtac has embarked on efforts to fully understand the relationship between blasting practices and mill performance. Optimizing the throughput and energy efficiency of the AG mills is the object of a 3-year study that has received funding from the Department of Energy (DOE) plus matching contributions from industrial partners. Following herein is a review of the developing study of blast/mill relationships at Hibtac.

Blast Design Factors

Identifying customers is a key part of any successful business. Blasting engineers must know who their customer is if they endeavor to produce the best product at the best price. The list includes

- Shovels have to dig the blast.
- Crushers must be able to efficiently comminute the rock without plugging.
- Mine operations must avoid excessive blast delays and safety problems.
- Neighbors must not be exposed to excessive airblast, vibration or dust.
- Mills must maximize throughput while minimizing energy consumption.

Failure to achieve any of these goals would critically compromise mining operations. Unfortunately, blasting to provide maximum mill throughput, while minimizing mill energy consumption, is a poorly understood relationship. Unless other important contributing factors including geological variation, crusher performance, seasonal temperature

variations, setpoints and operational parameters, and maintenance issues, are recorded and comprehended, blast design effects will simply be part of the "noise" in the sea factors influencing mill performance. As a result, few metal mines have capitalized on the economic potential of energy optimization.

PREVIOUS WORK

Grinding theory dates back to 19th century Germany where Rittinger (1867) and Kick (1885) proposed models based on surface area and particle volume, respectively. Bond (1951) proposed a third theory of comminution, which is still widely used today. Schneider and King (1995) at the University of Utah recently demonstrated improved modeling of grinding circuits.

Overall blast/mill optimization has more recent roots. MacKenzie (1966) reported on costs in iron ore from drilling through crushing. Udy and Thornley (1977) reviewed optimization through crushing. Gold, Kennedy, and Gray (1987) tabulated and modeled overall mining cost related to blasting at Fording Coal. LeJuge and Cox (1995) reported overall costs in quarrying. Eloranta (1995, 2001) published costs in iron ore from blasting through grinding. Moody et al. (1996) related dig times, crusher speeds and particle size to fragmentation in quarry operations. Fuerstenau et al. (1995) used single-particle roll mill crushing to demonstrate a 10% energy savings in the drilling through grinding process by increasing powder factor by 25%. Paley and Kojovic (2001) detailed the complex relationship between blasting, crushing and grinding at the Red Dog zinc mine in Alaska. Modeling indicated that a tripling of the powder factor would save 25 to 30 million dollars in grinding annually.

Recent laboratory work has been aimed at tying mine and mill size reduction to common factors. These efforts include the work of Revnivtsev (1988), who related micro-cracks from blasting to energy use in subsequent crushing and grinding. McCarter (1996) quantified blast preconditioning through the use of an ultra fast load cell. Nielsen (1996) performed extensive grinding tests on preconditioned rock and demonstrated changes in Bond work indices of nearly 3 to 1.

BLAST FRAGMENTATION

Kuz-Ram Model

Five blast pattern designs used at Hibtac were modeled using the Kuz-Ram model (Cunningham 1983). Kuz-Ram modeling is a simple, empirical model that predicts fragment sizes for varied blast parameters. Kuz-Ram is well suited to predict how changes in blast design will affect fragmentation relative to the results of the original design. Typical ore blasts at Hibtac have the following parameters:

- 40-foot depth
- 5 feet of subdrilling
- 18 feet of stemming
- water-resistant anfo blend (70/30)

Burden and spacing for the Kuz-Ram model is varied according to Table 1.

Applying the Kuz-Ram model to these parameters results in the following size distributions (Table 2).

TABLE 1 Burden and spacing for Kuz-Ram model

Design	Burden	Spacing
#1	38	44
#2	36	42
#3	35	40
#4	33	38
#5	31	36

TABLE 2 Kuz-Ram modeled size distribution

Size passing (Inches)	Design #1 38 × 44	Design #2 36 × 42	Design #3 35 × 40	Design #4 33 × 38	Design #5 31 × 36
0	0%	0%	0%	0%	0%
2	7%	7%	8%	9%	10%
4	14%	16%	17%	19%	21%
6	22%	24%	26%	28%	31%
8	30%	33%	35%	38%	41%
10	37%	40%	43%	46%	50%
12	44%	47%	50%	54%	58%
14	50%	54%	57%	60%	65%
16	56%	60%	62%	66%	70%
18	61%	65%	68%	71%	75%
20	66%	70%	72%	76%	80%
22	70%	74%	76%	80%	83%
24	74%	77%	80%	83%	86%
26	77%	80%	83%	86%	89%
28	80%	83%	85%	88%	91%
30	83%	86%	88%	90%	92%
32	85%	88%	89%	92%	94%
34	87%	89%	91%	93%	95%
36	89%	91%	92%	94%	96%
38	90%	92%	94%	95%	97%
40	92%	93%	95%	96%	97%
42	93%	94%	96%	97%	98%
44	94%	95%	94%	97%	98%
46	95%	96%	95%	98%	99%
48	95%	97%	95%	98%	99%

Reviewing these results, it can be seen that all five pattern designs supply an abundance of the coarse size fractions (greater than 6 inch). An adequate blend of coarse "media" rock is needed to act as balls or rods would in a conventional mill. Mill engineers have established the following specification for optimum autogenous milling at Hibtac: 40% 6–10-inch, 20% 3–6-inch, and 40% minus 3-inch. Compiling these distributions into the mill specification groups (Table 3), we see that design #5 most closely

TABLE 3 Kuz-Ram size distribution sorted according to mill feed specification

Size (Inches)	Design #1 38 x 44	Design #2 36 x 42	Design #3 35 x 40	Design #4 33 x 38	Design #5 31 x 36
minus 3 inch	12%	12%	11%	14%	15%
3 to 6 inch	14%	13%	12%	15%	16%
6 to 10 inch	17%	16%	15%	18%	19%
plus 10 inch	57%	59%	62%	53%	50%

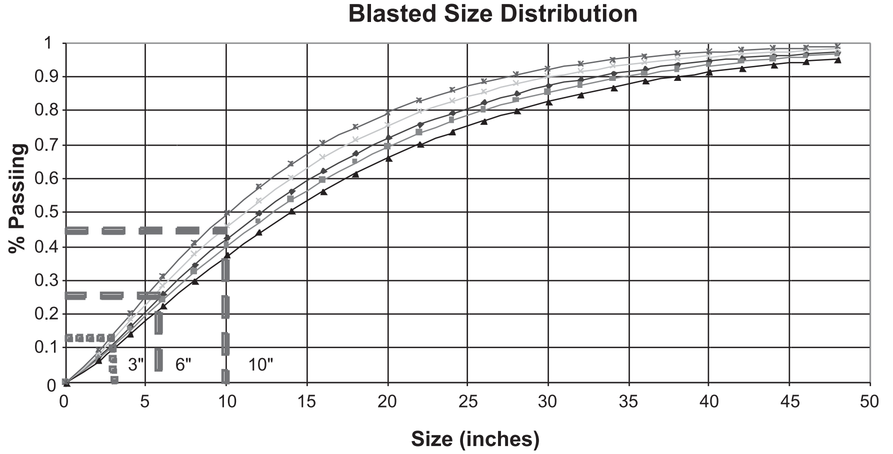

FIGURE 1 Size distribution for 5 Kuz-Ram models

matches the mill specification. It is interesting to note that design #5 has the highest powder factor due to the tighter burden and spacing.

Planned tests will attempt to verify these predictions. The challenge in blast design may be to maximize the minus 3-inch fraction while maintaining adequate 6–10 inch grinding "media" rock. Figure 1 is a plot of fragmentation results from the five modeled designs. All designs result in at least 50% plus 10-inch rock. Kuz-Ram predicts the high percentage of coarse fragments primarily because of the large burden and spacing used. Therefore, in the areas of the blast pattern furthest from the blast holes, the fragmentation is predetermined by the geology (joints, fractures, bed thickness, and lithology). This is much like toppling a brick wall, where the bricks distal to the point of impact are uncoupled rather than individually broken. However, in the areas close to the blast holes, significant fragmentation occurs.

Reviewing Table 3, it can be seen that even the most energetic blast falls short of producing the minimum amount of minus 3-inch feed, according to the mill specification of 20%. It should be noted that crushing normally does not generate a significant amount of fines. When the crusher breaks the plus 10-inch material, much of the product reports to the 6–10-inch category.

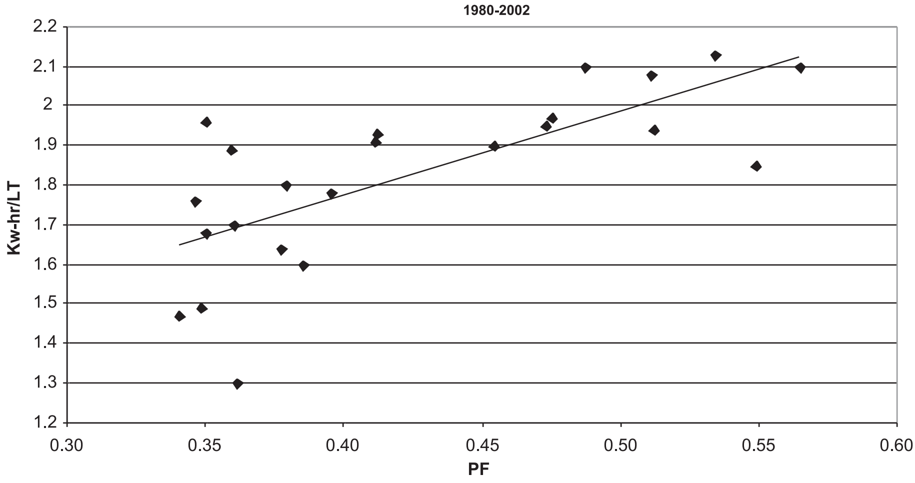

FIGURE 2 Crusher energy versus blast energy (powder factor in lbs powder/long ton)

HISTORICAL ANALYSIS OF BLASTING, CRUSHING, AND MILL PERFORMANCE

Hibtac production data from startup in the mid-1970s to the present is charted in this section. Numerous flowsheet changes, changes in mining areas and changes in blast design occurred over the past 3 decades, which makes interpretation difficult. However, fundamental efficiencies of each process in fragmentation may be evident.

Blast Energy and Crusher Energy

Figure 2 is a plot of annual powder factor in pounds of powder per long ton of ore versus the crusher kW-hr per long ton. Higher powder factors resulted in increased kW-hr/LT at the crusher. This may reflect an increased amount of finer fragments that tend to draw higher amps.

Crusher Energy and Total Energy

Figure 3 is a similar plot comparing kW-hr/LT for the crusher versus total Hibtac kW-hr/LT. Total energy consumption is dominated by milling. As crushing energy rises, total energy falls. The following observations may explain this phenomenon. Firstly, crushing is more efficient at producing surface area. Efficiencies in the order of 50% for crushing and of 1% for grinding have been estimated (Hukki 1975; Morrell et al. 1992). Secondly, finer blasting causes crusher amps to rise, while the mills' energy use per ton of feed may drop due to the additional minus 3-inch size fraction.

Blast Energy and Total Energy

Figure 4 compares total electrical usage at Hibtac to the energy imparted through blasting. Again, the inverse relationship may be due to the additional fines produced in

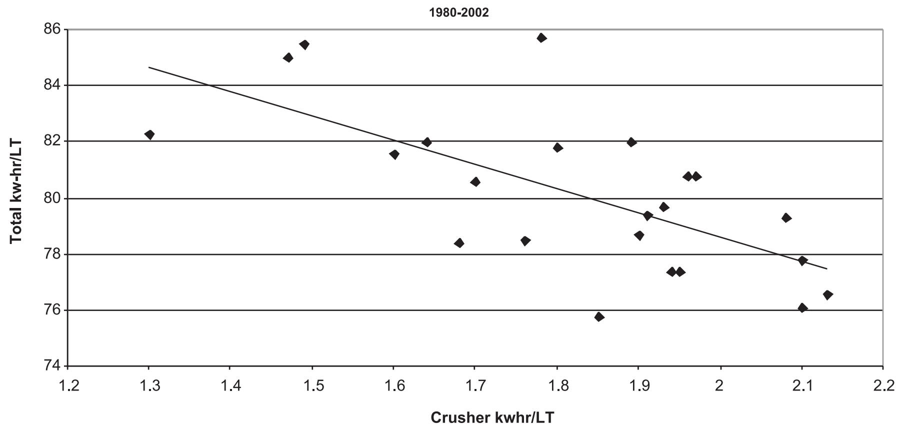

FIGURE 3 Crusher energy versus total energy

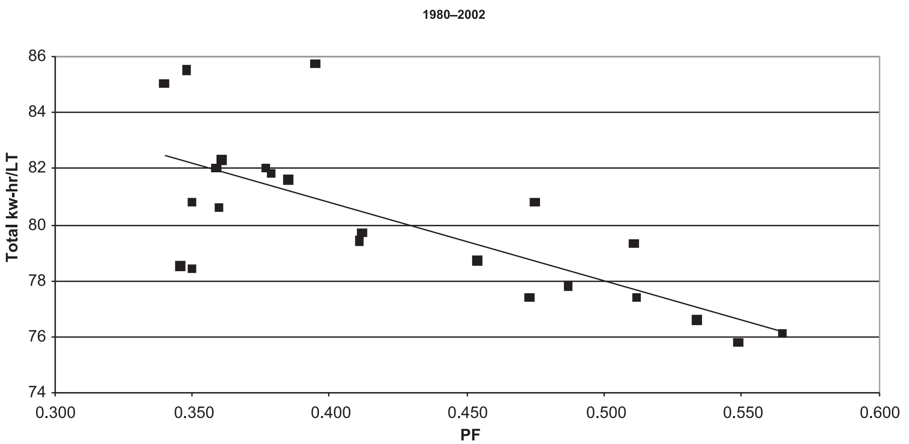

FIGURE 4 Blast energy (powder factor in lbs. powder/long ton) versus total energy

higher energy blasts. Crushing is not thought to generate a significant amount of fines, however the crusher draws higher amps with finer material and may end up doing more of the work at a higher efficiency compared to milling.

Modeled Energy Cost

Figure 5 assumes the cost of powder to be \$0.15/lb and the cost of electricity at \$0.05/ kW-hr. These costs are multiplied times the powder usage and the total electrical consumption, respectively. Total energy cost is the sum of electricity and powder costs. As powder factor rises, the sum of the cost of electricity plus powder declines.

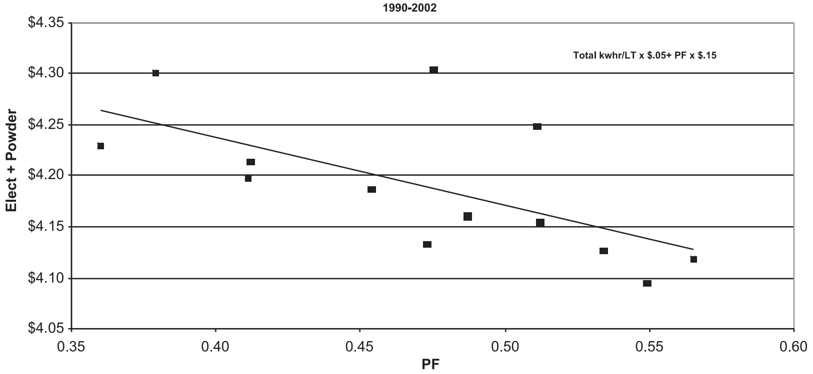

FIGURE 5 Total energy costs versus blast energy (powder factor in lbs. powder/long ton)

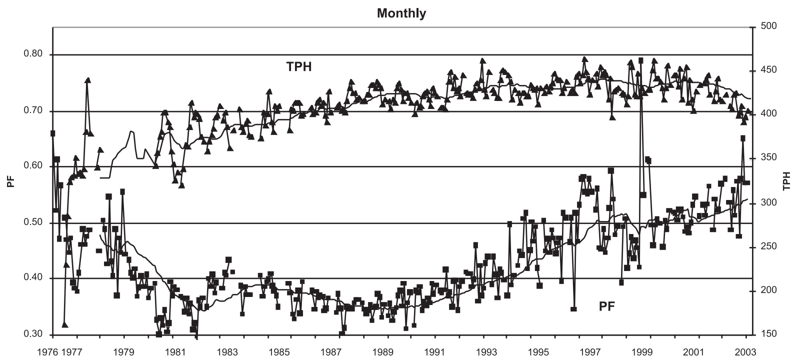

FIGURE 6 Mill throughput and powder factor

It appears that an increase of 0.20 in powder factor is associated with a $0.15/ton of product savings in electrical and powder factor energy costs.

Mill Throughput and Powder Factor

Figures 6 and 7 compare the history of powder factor and mill throughput. Figure 6 is a trend chart of mill tons per hour compared to monthly average powder factors since startup.

Figure 7 is an x-y plot of the annual results for the past 15 years comparing powder factor to mill tons per hour. With the exception of the year 2002, higher powder factors coincide with higher mill throughput.

Due to changes in all mining and processing areas, the apparent correlations in Figures 2 through 7 may or may not be significant. However, given the high cost of energy, continued investigation is appropriate.

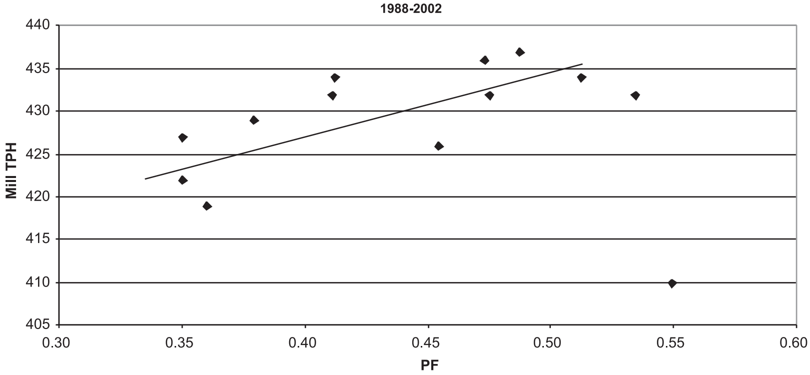

FIGURE 7 Powder factor versus mill productivity (tph)

In-situ Size Affects Mill Rate

Hibtac blast patterns are characterized by wide burden and spacings and low powder factors. As a result, the fragmentation level of run-of-mine rock may be largely a function of the frequency of joints and bedding planes. In order to begin to quantify in-situ fragment size, drill core was measured to model the percentage of material within different size fractions. Each core was broken into discrete geotechnical intervals that were measured for the cumulative lengths of pieces greater than 2 inches, greater than 4 inches, greater than 8 inches, and greater than 10 inches, and divided by the total length of the interval to determine the percentage of summed lengths of pieces (a technique similar to measuring for the rock quality designation—RQD). Care was taken to avoid measuring to obvious man-made fractures in the core box. Also, heavily oxidized intervals with poor core recovery do not reflect taconite ore and were not measured. From these measurements, additional bins were created that reflect the percentage of core pieces less than 2 inches, between 2 and 4 inches, between 4 and 8 inches, and between 8 and 10 inches. Through weight averaging, size distributions in the various geologic units were roughly modeled by mining area. Core length values were then assigned to historical daily mine production through reconciling blast patterns in the daily blend with weight-averaged geologic unit determinations from the nearest cluster of diamond drill holes. In this fashion, a daily weighted average of core length was generated. Figures 8 and 9 summarize core length versus mill throughput.

Core piece length measurements are a recent initiative at Hibtac, and the geotechnical database consists of only 42 diamond drill holes in four clusters marginal to the active mining areas. Therefore, the blasts are locally quite distant from the drill hole cluster on which their sizing model was based. Furthermore, all diamond drill holes at Hibtac are vertical, and the mostly steeply dipping joint sets were not consistently intersected. Also, the daily weighted fragment size data do not reflect sporadic contributions to crusher feed derived from active stockpiles to which no sizing model was applied. Despite these limiting factors, preliminary results suggest a possible correlation between core length and mill productivity. Decreasing mill throughput trends with increasing amounts of coarsely bedded material. Likewise, as the minus 2-inch portion rose, so did the mill throughput. These results do not seem to be consistent with the current mill demands for the coarsest possible feed, and may, through further investigation, shed

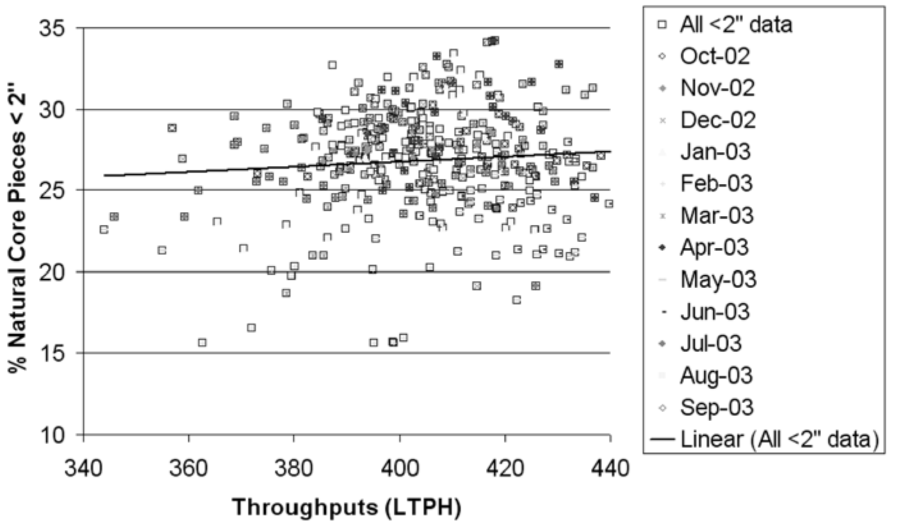

FIGURE 8 Mill throughput verses in-situ core lengths < 2″

new light on what constitutes optimum feed for autogenous milling. Geotechnical core measurements will continue, and as mining progresses into the areas with measured core holes, enough data may exist to warrant digital modeling of in-situ fragment size.

Figure 8 compares mill throughput to the percentage of mill feed represented by diamond drill core lengths less than 2 inches—fine material. Observations of core and in the field indicate this fraction is dominated by thin-bedded, slaty taconite sourced mainly from the lower ore units (1-4 to 1-3). The data covers 12 months of production, and exhibits much background noise that is likely due to the various other factors that impact mill productivity. It is difficult to draw conclusions from this except that additional fine material did not seem to hurt tons per hour, and perhaps even improved mill throughput.

The same noise exists for Figure 9, where mill throughput is compared to the percentage of mill feed represented by diamond drill core greater than 8 inches in length—coarse material. Observations of the core and in the field indicate this size fraction is dominated by relatively thicker bedded cherty taconite sourced from the upper, 1-5 to 1-7, ore units. Again, it is difficult to draw conclusions from the data except that a greater percentage of coarse material does not appear to increase mill throughput.

However, breaking up the charts into separate months suggests some stronger trends. Here, January and February 2003 are illustrated in Figures 10 and 11. In both cases additional fine material apparently enhanced mill productivity, and additional coarse material apparently depressed mill productivity.

This trend wasn't universal for the 12 months studied. Over the period of one year, 6 months showed a similar pattern as the above, 4 months were neutral, and 2 showed a reversal of the trends.

Again, the database for in-situ core length is small, and several of the blasts were located a significant distance from the representative drill core. However, these preliminary results are encouraging and call for further investigation.

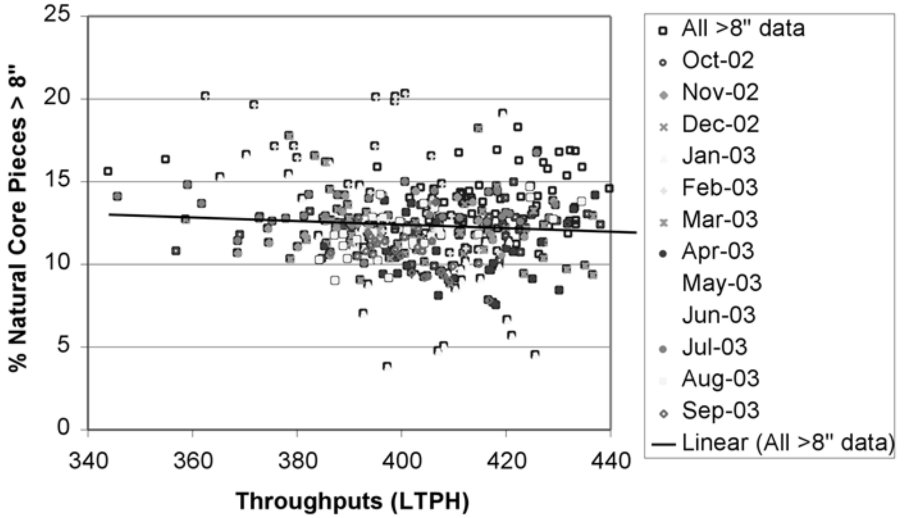

FIGURE 9 Mill throughput versus in-situ core lengths > 8″

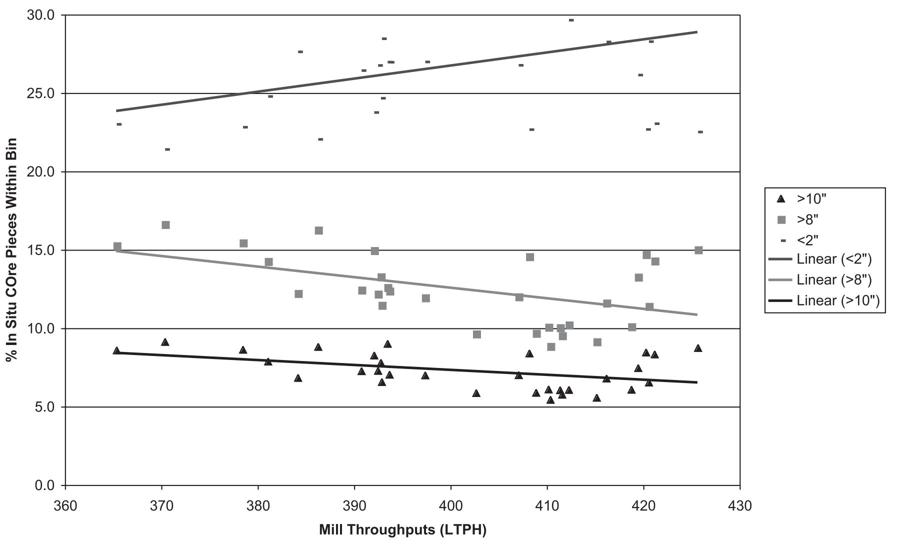

FIGURE 10 Mill throughput versus thin and thick bedding in-situ core length, for January 2003

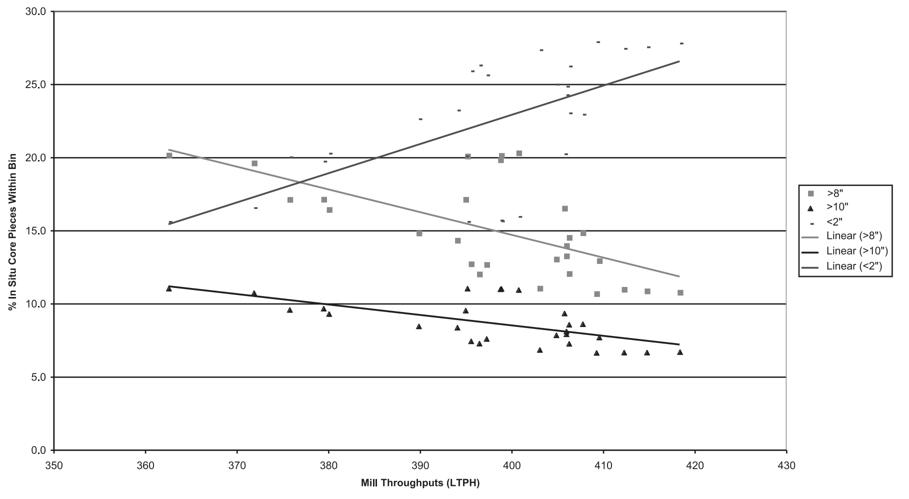

FIGURE 11 **Mill throughput versus thin and thick bedding in-situ core length, for February 2003**

CONCLUSIONS

Initial results are very encouraging. Although increasing powder factors will push mining costs up, the potential to improve overall costs and performance is indicated by the following conclusions:

1. In Hibtac's large spacing blasts, fragmentation is predetermined by in-situ bedding, jointing and fragment size, and powder factor plays a secondary role.
2. Models of all current Hibtac blast designs produce excessive amounts of plus 10-inch fragments. None of the designs produce even one-half of the minus 3-inch material called for in the mill feed specification.
3. Blast fragmentation modeling indicates that higher powder factor designs may match mill specifications more closely than low powder factor designs.
4. Bedding thickness affects mill productivity. Thicker beds produce larger fragments that tended to depress throughput, while thinner beds yield higher tons per hour.

The next step is the design of a series of tests involving increased powder factors and measurement of both mill performance and fragmentation. If these early indications prove to be correct, Hibtac blasting and milling practices may be poised for improvements.

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Mining Company Performance Improvement Programs and Results—Summary of Benchmarking Study

Peter Fordham*

A Norbridge review of 25 top mining companies highlighted financial problems for many firms. To better understand these results, Norbridge benchmarked 17 mining companies to understand the problems that companies face, the methods being used to improve performance, and the results that have been achieved.

The study indicates that many mining companies in three sectors—coal, metals, and non-metallic minerals—have implemented new strategies to improve performance. Many of these strategies supplement traditional initiatives with two types of process improvement efforts, facility-specific and company-wide, to help generate performance gains. The study compares the results of these strategies in each sector.

INTRODUCTION

Times are tough in the mining industry. Norbridge reviewed financial results of 25 top mining companies for the past 2 years—seven coal companies, twelve metals companies, and six non-metallic minerals firms.† The study found that 40% lost money in 2002, and

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* Norbridge, Inc., Concord, Mass.

† Coal companies include Alliance Resource Partners, Arch Coal, Consol Energy, Massey Energy, North American Coal, Peabody Energy and Westmoreland. Metals producers include Barrick Gold, Cleveland-Cliffs, Coeur d'Alene, Falconbridge, Freeport McMoran, Grupo Mexico, Inco, Newmont Mining, Noranda, Phelps Dodge, Placer Dome, and Teck Cominco. Non-metallic firms include Florida Rock, IMC Global, Martin Marietta Materials, Oglebay Norton, PotashCorp and Vulcan Materials. Information is from public sources, e.g., annual reports, company Web sites.

48% lost money in 2001. In addition, 52% of the companies had worse financial results in 2002 than 2001. The industry is struggling to maintain the financial foundation necessary for future investment.

The analysis focused on three mining industry segments: coal, metals, and non-metallic minerals. Each sector faces significant financial challenges. Coal performed best in 2001 and 2002, with 29% of coal companies losing money in each year. Non-metallic minerals firms were next, with 33% losing money. Metals companies performed worst, with 50% of companies unprofitable in 2002 and 67% unprofitable in 2001.

To better understand these problems, Norbridge conducted a benchmarking study with 17 of the largest mining companies, including six coal producers, seven metals companies, and four non-metallic minerals firms. A list of the benchmarking participants is shown below.

Benchmarking Participants

Coal (6 companies)

- Arch Coal
- Consol Energy
- Kennecott Energy
- Kiewit Mining Group
- North American Coal
- Peabody Energy

Metals (7 companies)

- Climax Molybdenum
- EVTAC Mining
- Falconbridge
- Freeport McMoran Copper and Gold
- Inco
- Placer Dome
- Anonymous Mining Co.

Non-Metallic Minerals (4 companies)

- Hanson Building Materials America
- IMC Global
- Martin Marietta Materials
- PotashCorp

The specific focus of the study was on performance:

- What problems are preventing companies from improving their financial performance?
- What types of strategies are companies using to improve their performance?
- What performance levels, or results, are being achieved with the different strategies?

Benchmarking results for each question are summarized below.

TYPICAL MINING COMPANY PROBLEMS

Companies in all industry sectors identified a consistent set of problems that are holding them back from improving performance. These problems are in three main categories: (1) corporate level, (2) facility level, and (3) performance measures.

At the corporate level, many companies are having trouble getting the next generation of production gains and cost reductions. While many firms have been very successful at cutting costs and improving productivity over the past 10–15 years, they have recently begun to face problems. Furthermore, at a time when companies need capital to help them improve performance, money is tight. Many businesses are not generating enough cash to invest where and when they need to, and are having trouble attracting potential investors. Additional problems faced by many companies include reserve depletion, an aging workforce, and a "plateau" in safety performance.

At the facility level (mines and processing plants), many companies are having trouble with the "basic building blocks" of mining performance. Many companies indicated problems with planning, teamwork, standard operating procedures, communication, maintenance, materials and other areas that need to be on target for strong facility performance.

Many respondents also indicated that performance measurement systems are a problem. In many cases, a broad set of integrated performance measures do not exist or are not used very proactively to identify problems. Measures are also very focused on "results" that have already occurred (e.g., production, cost, safety), not "leading" or "early warning" indicators to tell managers how well their processes are performing, or how these processes are likely to impact future performance levels. In addition, performance results are often not distributed very widely, or are not sent to key managers or decision makers.

MINING COMPANY STRATEGIES TO IMPROVE PERFORMANCE

Norbridge spoke with respondents about what they are doing to "turn things around." Traditionally, mining companies have been very focused on mergers and acquisitions, corporate restructuring and downsizing, and capital investment for bigger, faster, stronger equipment. While these types of strategies are still important, benchmarking indicates a new focus on *process improvement* to supplement these more traditional types of initiatives and to "jump start" performance levels.

In order to improve their processes, companies are generally following one of two separate and distinct paths. The first path is a "bottom up" approach—focusing on facility or issue-specific projects to address problem areas or opportunities for improvement. This path includes facility-specific "game plans" to address the specific needs or problems of a mine or processing plant—for example, planning, communication, teamwork, or other areas that represent the "basic building blocks" of success at mining facilities. It also includes sharing best practices across mines and plants, as well as a variety of issue-specific initiatives to address opportunities for improvement—for example, safety, maintenance, belts or other areas. This path tends to be based on smaller, more "bite size" projects, which typically take only a few months and limited people and financial resources to complete.

The second path is a "top down" approach—focusing on large corporate improvement programs like Six Sigma, Change Acceleration, or Business Process Improvement.

These programs are generally major corporate initiatives, requiring multi-year commitments and significant resources—dollars and people—to complete. Large numbers of employees—often in the hundreds—are typically trained and become part of employee teams that address numerous projects in different business units.

In total, about two-thirds of the 25 companies evaluated have the smaller project focus (Path 1) and about one-third have large corporate improvement programs (Path 2). However, the characteristics of each mining sector are different, particularly coal versus non-coal. Only 13% of coal companies are in Path 2 versus 44% of non-coal companies, and the number of non-coal companies with large programs continues to grow. By sector, one-third of non-metallic mineral firms and one-half of metals producers are in Path 2.

The sector difference may reflect that non-coal mining companies, particularly metals producers, are struggling more financially than coal producers and feel a more compelling need for a large program (Path 2) to "turn themselves around." It may also reflect that some coal companies have tried some of the larger process improvement programs in the past with limited results. For whatever reason, the three sectors of the mining industry do seem quite different in this area.

EXAMPLES OF PATH 1 AND PATH 2 PROGRAMS

Path 1 includes two types of initiatives—facility-specific and issue-specific. Three examples of facility-specific initiatives are based on the development of "game plans" to improve performance:

1. At an underground mine, a mining company implemented a game plan to improve performance that addressed standard operating procedures, communication, loading time lost, performance measures, and other areas that they considered problems. The result was an increase in their capacity utilization from around 60% to around 70%.
2. At another underground mine, a mining company implemented a game plan that addressed a wide range of issues and problems, similar to those outlined above; feet mined per unit shift increased by 26% and costs declined by 9% after development and usage of the plan.
3. At a processing plant, a mining company implemented a game plan to improve performance that looked at maintenance, operating schedules, performance measures and other areas. The result was a rise in plant availability from the high 70s/low 80s to consistently above 90%, even while plant utilization was rising significantly to above the 90% level due to a big increase in throughput. They also cut their magnetite usage by two-thirds, resulting in annual savings of more than $0.5 million.

Three examples of issue-specific initiatives include

1. One company focused significant attention on their belt availability, which led to a 3%–4% increase in availability levels across the company
2. Another company conducted a benchmarking study of truck/shovel operations that led to implementation of process and equipment changes. Productivity rose from "middle of the pack" to "top 10%."

3. A third company is turning “large” mines back into “small” mines. They are sealing old entries and creating new entries to allow removal of coal closer to where it is mined, with the expectation of significant “overhead” cost reduction.

Path 2 consists of large corporate improvement programs. Examples include

- Phelps Dodge—Quest for Zero Program
  - “Quest for Zero gives employees a set of tools and principles that allows them to work systematically toward zero safety and environmental incidents, zero variability in production processes and costs, zero waste, and zero product defects”—Phelps Dodge, 2002 Annual Report, Page 3
  - “Most Quest for Zero projects are smaller in scale, but all have a measurable economic payback. The program is literally about hundreds of these types of projects in every business unit.”—Phelps Dodge, 2002 Annual Report, Page 3
  - “We introduced Quest for Zero in 2001 and realized $55 million in annual improvements. During 2002, we gained an additional $211 million in improvements, ending the year at a run rate approximating $250 million... It will take great effort, but our intent is to use Quest for Zero to increase our sustainable annual improvements to $400 million in 2004.”—Phelps Dodge, 2002 Annual Report, Pages 3-4
- Cleveland-Cliffs—ForCE 21 Program
  - “ForCE 21 is a way of helping us all move in the same direction. By standardizing the ways we work, we will be working smarter and living better.”—Cleveland-Cliffs Corporate Web site
  - “We have utilized almost 100 CAP (Change Acceleration Process) teams since the commencement of the program in April 2000 and have trained hundreds of employees to be members of CAP teams.”—Cleveland-Cliffs, 2002 Annual Report, Page 3
  - “Mine operating costs, excluding costs of production curtailments, were down by 5 percent compared to 2001 costs... The teams provided over $7 million in cost-reduction benefits on an annualized basis in 2002.”—Cleveland-Cliffs, 2002 Annual Report, Page 3
- IMC Global—Six Sigma Program
  - “The foundation for our continuous improvement program was put in place about 3 years ago with the implementation of a Six Sigma system. This encompasses a rapidly growing number of ‘black belt’ and ‘green belt’ employees, some 250 at this writing, who are improving product quality, customer service levels, and cost.”—IMC Global, 2002 Annual Report, Page 10
  - “Our Six Sigma program delivered cost savings in excess of $8 million in 2002 from more than 60 projects.”—IMC Global, 2002 Annual Report, Page 10

MINING COMPANY RESULTS BY STRATEGY

While either type of strategy can generate strong financial performance, mining company results differ by strategy in two areas: (1) 2002 financial results and (2) improvements in financial results from 2001 to 2002.

On an annual basis, 71% of Path 1 companies—focused on smaller process improvement projects—were profitable in 2002 versus 38% of Path 2 companies. This disparity is also evident by mining sector. For coal, 83% of Path 1 companies were profitable versus 0% for Path 2 firms, though most coal companies are Path 1. For non-metallic minerals, 75% of Path 1 companies were profitable versus 50% for Path 2. For metals, 50% of companies were profitable in each path.

Path 1 companies also improved their financial performance from 2001 to 2002 at a higher rate than Path 2 companies. Overall, 59% of Path 1 companies improved their financial performance in 2002, versus 25% of Path 2 companies. This disparity was again consistent by mining sector—67% to 0% for coal, 25% to 0% for non-metallic minerals, and 67% to 50% for metals.

CONCLUSIONS AND RECOMMENDATIONS

Mining companies are exploring new avenues to improve their financial performance. In particular, many companies are supplementing their traditional performance improvement approaches with a new emphasis on process improvement.

While many companies are making progress in fortifying their financial foundations, companies focused on Path 1 (facility- and issue-based process improvements) have so far outperformed companies focused on Path 2 (large corporate programs). Path 1 companies have also typically generated these better results with smaller investments in people, time, and money than their Path 2 counterparts.

Further research is needed to determine the specific causes of this performance disparity, whether the trend is short term or long term in nature, and whether other causes are driving the difference. It is also important to understand whether the "path" that a company selects is a *cause* or an *effect* of their financial results. In addition, since some programs, particularly in Path 2, have been implemented in recent years, it may take more time to leverage corporate capabilities and generate expected benefits.

Management Systems for Operations Improvement

or

Management Systems That Actually Work (No Harvard MBAs Allowed!)

How Good Is My Maintenance Program?

John D. Katsilometes*

In the mining and processing industry, the maintenance plan has often evolved rather than being consciously set up resulting in an overreliance on breakdown and fixed-time maintenance (planned maintenance). Historically mining and processing plant equipment has been robust and less automated than modern equipment, making it relatively easy to work on. Mining and processing plants have relied on large and expensive maintenance departments to enable rapid attention to breakdowns.

Maintenance itself can result in excessive downtime and costs. This results from the requirement to take the machinery off-line to carry out (possibly unnecessary and invasive) maintenance. The danger of infant mortality after it has been put back on line again and also the cost of the maintenance action itself contributes to costs.

A goal of any well-run maintenance program is to have the lowest cost while providing 100% capacity 100% of the time to operations. When maintenance investments are at a minimum, the cost of lost production is at its highest. As maintenance effort and investments are intelligently increased, the production loss gradually decreases until the lowest combined cost is achieved. This is the maintenance goal.

A road map is needed to achieving maintenance excellence.

This article addresses a "Road Map" to achieving maintenance excellence.

INTRODUCTION

Mining and processing industry maintenance is big business. A world-class maintenance program is characterized by maintenance excellence.

* Cleveland-Cliffs Inc., Cleveland, Ohio

What is maintenance excellence?

- Organizing and MANAGING an
  - **Efficient** maintenance program
  - **Effective** maintenance program
  - **Employee-involved** maintenance program

A world-class maintenance program assures 100% capacity 100% of the time to the operation.

A world-class maintenance program gets the respect it deserves and the support it needs. Maintenance is big business and maintenance is a full-time partner in the mining and processing venture.

Here are some interesting statistics about maintenance programs:

- Most maintenance departments in the US and Canada operate between 10%–40% efficient.
- 70% of equipment failures are SELF-INDUCED.
- ⅔ of all companies do not have maintenance planners.
- Less than 10% of these planners are utilized efficiently.
- Most maintenance organizations are either dissatisfied with or do not use a work order system.
- Only 10% of companies with a work order system utilize performance monitoring.
- Only 10% of companies with a work order system perform failure analysis.
- 14% of total time worked by maintenance is on overtime.
- Only 22% of all companies are satisfied with their current PM program.
- Maintenance material costs can range from 20%–70% of the maintenance budget.
- 50% of maintenance departments manage the maintenance storeroom inventory.

MAINTENANCE EXCELLENCE

There are a variety of maintenance models. A good friend of mine once told me “there are a whole lot of ways to run a maintenance program and most of them are wrong!” Here are some characteristics of a few maintenance models:

Traditional Model

- Operations owns production, maintenance owns equipment.
- Maintenance excellence means efficient service (e.g., repairs) to production. A customer service model dominated by operations.
- Repair efficiency is the best measure of maintenance performance. No time to do it right, but hope there is time to do it over.
- Production runs at any cost. Don’t have time to turn equipment over to maintenance as scheduled.

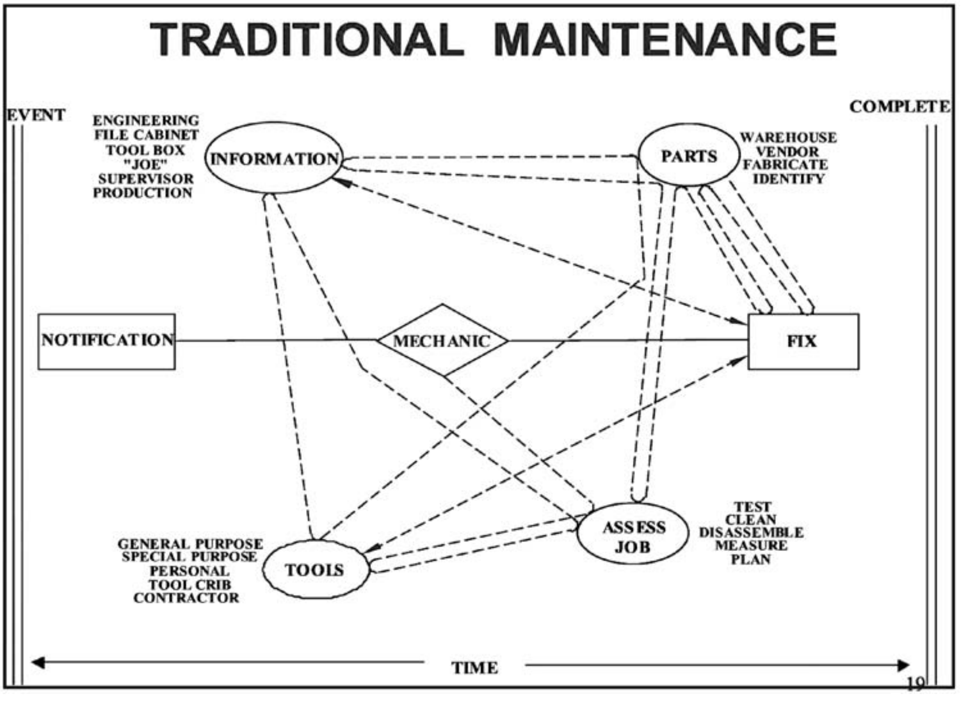

FIGURE 1 Traditional model work flow

- Goals are set by functional managers, resulting in contradictory and self-defeating reward/recognition practices. Most measures are lagging indicators, demonstrating past results.
- Purchasing excellence means having the lowest cost of items available.
- Pressure is on individuals to do better. No gauges or tools of "better" exist.

In the traditional model the **event** happens and then the activities begin. The result of this type of maintenance is that it is reactive in nature and high in cost. Capacity and capacity assurance suffer.

Excellence Model

- Operations owns equipment and is responsible for equipment health.
- Maintenance is a partnership with operations to identify and work out ways to improve equipment health.
- Breakdowns represent an unacceptable management system failure and require failure analysis of equipment and process.
- Production insists on and participates in assuring prevention and improvement activities.

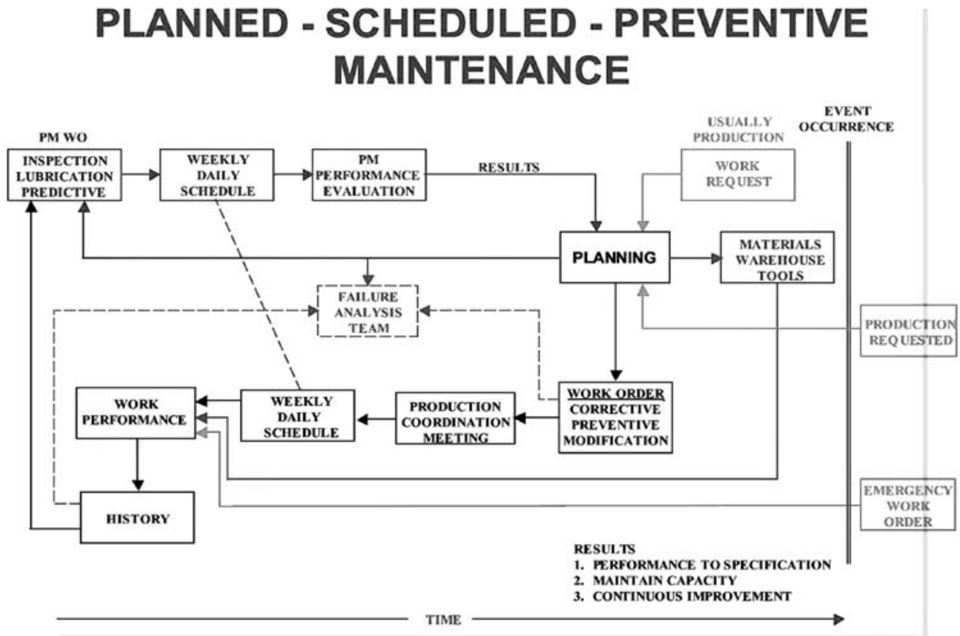

FIGURE 2 Excellence model work flow

- Goals are developed top-down in a cascaded fashion. Functions share lagging indicator goals (e.g., monthly production) and have unique leading indicator goals that support activities (e.g., % of PMs performed to schedule).
- Purchasing and inventory management's highest goal is parts service level and MTBF for purchased parts.
- Each piece of equipment has an operating performance specification and gets the attention necessary for it.
- The maintenance department manages the maintenance storeroom inventory.

The excellence model is proactive. In the excellence model the only reactive **events** that happen are when production requests a priority job to be done or emergency work is necessary. This model of maintenance is proactive in nature and low cost. Capacity is assured.

Maintenance Program Assessment

It is a good idea to assess your maintenance department. If your operation has a maintenance process standard, the assessment can be derived from the elements of the standard. If not, an assessment can be developed from the ground up.

At Cleveland-Cliffs, there is a Maintenance and Operations Process Standards work process document. From this standard, we constructed a maintenance program assessment for our sites. We used the classic five-stage maintenance pyramid as our template for mapping our progress:

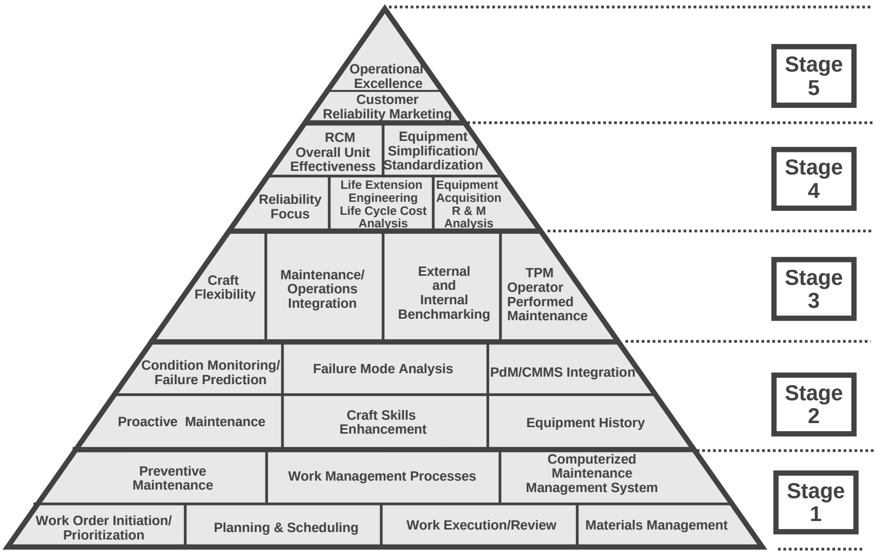

FIGURE 3 Work management processes form the foundations of world-class maintenance organizations

We then established an assessment criterion:

Definitions

Factor. The factor is the Cleveland-Cliffs Maintenance Leadership Team ranking of a process activity. A factor of 25 would indicate the process activity has the highest factor ranking. A lower process factor of 20, 15, 10 or 5 would indicate the activity is ranked accordingly lower. Rankings are as follows:

- 25 is the highest factor-ranked activity
- 5 is the lowest factor-ranked activity

Index

Index Codes	Explanation
0 Index Points	No visible program/process in place during the baseline assessment.
1–3 Index Points	Beginning of a program/process but requires a major emphasis to bring up to an acceptable level.
4–6 Index Points	Program in place but requires improvement to bring up to an acceptable level.
7–8 Index Points	Program/process in place but requires minor refinement to bring up to an acceptable level.
9 Index Points	Program/process in place and is adequate for the existing operational level.
10 Index Points	World-class program/process

Value. The value is the product of the index points and the factor.

MLT baseline performance rating. The MLT baseline performance rating is the calculated overall rating taking all the categories, index points, factors and values into consideration. The MLT baseline performance rating is merely a baseline to leverage certain areas for opportunity for equipment management and maintenance process improvement.

Using the following color codes, pyramids were constructed to reflect the progress of Cleveland-Cliffs maintenance program at our sites. The following is an example from one of our sites.

Color Coded Index and Percentage Compliance to World Class

- **No visible program exists (0 Points)**
- **Beginning of a program, major emphasis to bring to an acceptable level (1-3 Points)**
- **Process in place, improvement required to bring to an acceptable level (4-6 Points)**
- **Process in place, minor refinement to bring to an acceptable level (7-8 Points)**
- **Adequate for existing operational level (9 Points)**
- **World Class (10 Points)**

An example of a site maintenance assessment:

Maintenance Process Assessment Document

	Cleveland-Cliffs Inc						
	Maintenance/Operations Process and Standards						
	MLT Process Baseline Assessment						
	MLT Baseline Performance Rating =			6.6			
Site: Cliffs & Associates LTD	Date: 16 July 2002						
Prepared By: Cecil Andalcio							
					Section detail		
		Index	*Factor*	*Value*	Factor	Value to	Average
MPS 1 Mission and Vision							
Mission and Vision	Posted	9	15	135			
Mission and Vision	Communicated	8	15	120			
Mission and Vision	Current	8	15	120			
Mission and Vision	Referenced to MLT	8	15	120			
Mission and Vision	Training Provided	8	15	120			
					75	615	8.20
MPS 2 Corporate MLT							
Corporate MLT	Designated site representative	9	20	180			
Corporate MLT	MLT Calendar time	6	25	150			
					45	330	7.33
MPS 3 Local MLT							
Local MLT	Representation	7	25	175			
Local MLT	Calendar Time	6	25	150			
Local MLT	GM/AGM membership	6	20	120			
					70	445	6.36
MPS 4 MLT MPS Active Support							
MLT MPS Active Support	Completely committed	7	25	175			
MLT MPS Active Support	Supports safe maintenance	8	25	200			
MLT MPS Active Support	GM/AGM meeting attendance	7	20	140			
					70	515	7.36
MPS 5 Roles and Responsibilities							
MPS Roles and Responsibilities	Employees	8	10	80			
MPS Roles and Responsibilities	Organizational alignment	8	10	80			
					20	160	8.00
MPS 6 Training							
Training	40 hour/year/employee	9	25	225			
Training	Leadership	9	15	135			
Training	Task	5	20	100			
Training	Documented	8	10	80			
Training	Orientation	9	20	180			
Training	Federally mandated	8	25	200			
Training	Knowledge based	9	20	180			
					135	1100	8.15
MPS 7 Work Orders							
Work orders	Usage	7	25	175			
Work orders	Coding	7	25	175			
Work orders	Identification, work	6	25	150			
Work orders	Estimation	6	25	150			
Work orders	Closure	6	25	150			
Work orders	Actual vs. estimates	5	20	100			
Work orders	Blanket WOs minimized	9	20	180			
Work orders	Computer standardization	7	25	175			
Work orders	WO flow chart	8	25	200			
					215	1455	6.77

FIGURE 4

The site summary

Maintenance Process Assessment Summary

Stage 1		
Work Order Initiation/ Prioritization	6	
Planning and Scheduling	7	
Work execution	6	
Material Management	7	
Preventive maintenance	8	
Work management processes	7	
CMMS (MP5);	8	Very functional; all staff basic training; good utilization
Stage 2		
Proactive maintenance	5	
Craft skills enhancement	8	
Equipment history	7	
Conditioning monitoring/ Failure prediction	8	
Failure Mode Analysis	2	
PdM / CMMS intregation	3	Inspection module is in set up stage, this addresses requirements
Stage 3		
Craft Flexibility	7	Cross functional training in progress,.
Maintenance / Operations Integration	6	
External / Internal Benchmarking	7	
TPM / Operator performed Maintenance	8	
Stage 4		
Reliability Focus	5	
Life Extension / Life cycle cost Analysis	8	
Equipment Acquisition /R&M Analysis	7	
RCM & Overall unit effectiveness	3	Beginings of a program in place, cause, failure, action codes in plac
Equipment specification and Standardization	7	
Stage 5		
Customer Reliability Marketing	1	
Operations excellence	7	

The color-coded site maintenance Pyramid for 2000:

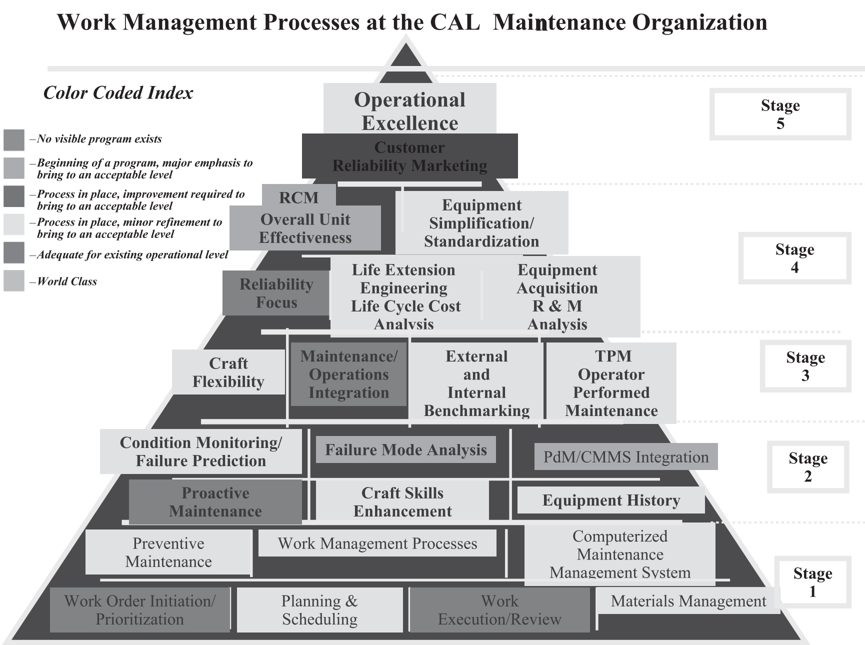

FIGURE 5

The Maintenance Pyramid has 5 stages.

Stage 1

Planned maintenance. Planned maintenance work is found to be three times more efficient than unplanned work. Maintenance organizations implementing planned maintenance systems will design and document a new work management process, incorporate any changes to a maintenance management system, and assure, through training and coaching, that work is properly planned, scheduled and executed. Changes may have to be made in the preventive maintenance process to assure that PMs are providing the desired results. Further enhancement of the work management process can be made by clearly identifying roles and responsibilities, setting expectations and coaching to meet performance objectives.

Stage 2

Proactive maintenance. This stage builds upon the success of daily maintenance. Using RCM techniques the preventive and predictive maintenance system is redesigned. By employing condition monitoring and predictive techniques, failure events begin to reduce. Failure prediction is accomplished by using equipment history to identify time-based failures. Through a consistent program of failure analysis, failure modes are eliminated or mitigated.

Stage 3

Organizational excellence. Exploring the resources outside of maintenance and engineering to improve reliability plays a central role in Stage 3. In most cases operators can play a far greater role in managing equipment health than they do. By Stage 3 there is enough control of the work and the equipment that decentralizing some of the maintenance staff is valuable. Teams of operators and craftsmen increase the effectiveness of all the area work, and the operators learn to accept and perform some of the work that was performed by the craftsmen. The craftsmen gain a better understanding of the equipment operating requirements and characteristics.

Stage 4

Engineered reliability. The intention of engineered reliability is to proactively eliminate both failure modes and the need to maintain against failure modes. If in earlier stages maintenance organizations engaged in preventive maintenance, maintenance organizations are now looking at maintenance prevention. By Stage 4, maintenance organizations have systematically become more effective in their repair efforts. Maintenance organizations are now minimizing the impact of equipment failures and are using all of their resources to identify equipment problems and maintain equipment condition. They are now able to tackle and effectively execute more complex equipment tasks.

Stage 5

Operational excellence. Experience shows that operational excellence is highly dependent on equipment reliability. In this stage, maintenance organizations develop a comprehensive approach to asset management. This approach integrates the cycle of annual business planning with the equipment condition necessary for each unit to meet the requirements of the business plan. At this stage, maintenance organizations evaluate equipment criticality of all systems, identify the current condition of all components, develop operating specifications for all systems and components, and develop a zero-based maintenance strategy for each component in the plant.

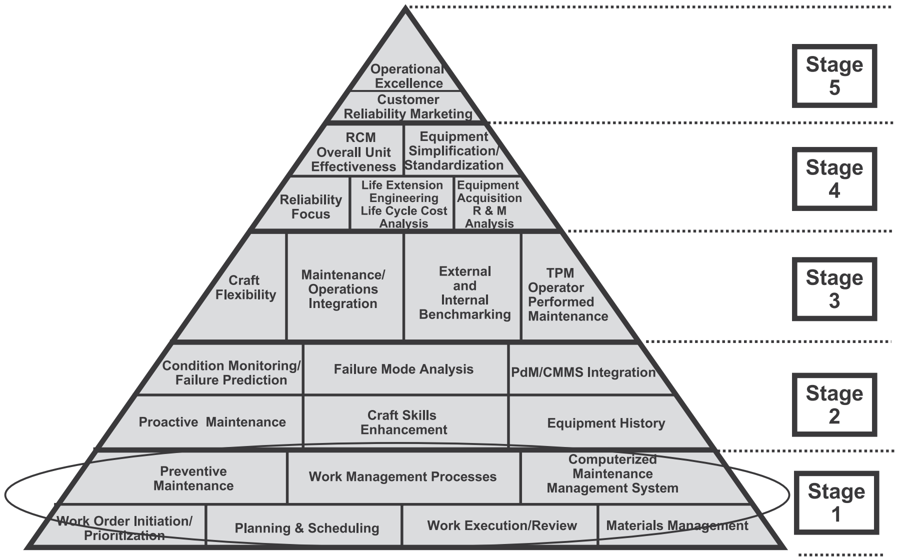

FIGURE 6 Work management processes form the foundation of world-class maintenance organizations

The importance of Stage 1:

- Preventive Maintenance
- Planning and Scheduling
- Work Execution/Review
- Work and Work Order Initiation/Prioritization
- Work Management Processes
- Computerized Maintenance Management Systems
- Materials Management

If you derive nothing else from this paper it is

When you become world-class at Stage 1, your maintenance program is better than 95% of maintenance programs.

In the best selling book *Good to Great* this is referred to as the "Hedgehog Concept." World-class maintenance programs put supreme significance on doing Stage 1 at world-class levels, consistently, 100% of the time.

How Do I Measure My Maintenance Program?

Here Are Some Maintenance Metrics:

- Physical availability
- Asset efficiency
- MTBF (mean time between failure)
- MTTR (mean time to repair)
- Total capacity vs. actual capacity
- Backlog = All work requested in man-hours
- PM compliance = PMs completed/PMs scheduled
- Schedule compliance (performance) = Man-hours required/man-hours scheduled
- Rework = Tasks repeated due to improper execution
- Emergency work = Any work that is not planned/scheduled
- Units produced/maintenance man-hour
- Total inventory value = $ value of all parts and materials
- Monthly inventory usage = $ value of all parts and materials used monthly
- Overtime = Overtime hours/crew and/individual
- Emergency purchases = Any parts or materials bought on a rush basis
- Stockouts = Parts available/parts requested
- Total cost = All direct and indirect costs/units produced
- Maintenance cost = All labor and materials cost/units produced and maintenance cost/equipment item
- Maintenance man-hours vs. non-maintenance man-hours
- Energy costs = All energy cost broken down by commodity/units produced
- Maintenance cost as % of replacement value

Some World-Class Maintenance Metrics:

■ Planned/scheduled	91%
■ Breakdowns	2%
■ Overtime	1%
■ Inventory level	½ Typical
■ Backlog (front log)	5.5 Weeks
■ Budget performance	Var. 1%–3%
■ Capital replacement	Low
■ Stockouts	Minor
■ Physical availability	96%
■ Asset efficiency (mobile)	86%

■ PM and servicing accuracy vs. target	±10%
■ Major component replacement planning accuracy vs. target	±10%
■ Major component life	150% of OEM projected
■ Maintenance manpower mobile (repair man-hours/operating man-hours)	0.3
■ MTBF	(75–100 hours mobile)
■ MTTR	(3–6 hours)

Some Maintenance Excellence Goals:

■ Maintenance craft per first line supervisor	= 8–12
■ Maintenance craft per planner	= 20
■ Maintenance craft per maintenance engineer	= 40
■ Maintenance craft as % of total plant hourly	= 15%
■ Maintenance cost as % of replacement value	= 5%
■ Maintenance labor cost as % of total maintenance costs	= 30%
■ Breakdown man-hours	= 10%
■ Preventive/predictive man-hours	= 30%

Some Maintenance Program Best Practices:

- 100% of a maintenance person's time is covered by a work order
- 100% of maintenance materials are covered by a work order
- 90% of corrective work orders result from PM inspections
- 30% of all labor hours are PMs
- 90% of planned/scheduled work compliance
- 100% PM compliance
- 100% capacity is reached 100% of the time
- Spare parts stockouts are rare (less than one per month)
- Overtime is less than 2% of total maintenance time
- Maintenance budget is within ±2% per piece of equipment
- Proactive Maintenance is **the Mission**

SUMMARY

There are no "Silver Bullets." In order to achieve maintenance excellence, a solid foundation must be a requisite. World-class maintenance programs put supreme significance on doing Stage 1 of the process at world-class levels, consistently, 100% of the time.

The Best of the Best then take the next steps (2–5) and complete the process of achieving world-class levels of performance for all 5 stages of the process.

Value Creation Through Effective Project Management

William S. Brack*

The mining industry is very capital intensive. Competition for shareholder investment has never been greater. Among our challenges is the need to meet shareholder expectations (return on investment), and one area of focus lies in our ability to deliver value on our capital investments. Our ability to meet project expectations affects not only the economics associated with the immediate project but also directly influences our ability to finance future projects. Moreover, our ability as individual companies to attract investor capital is influenced by how we have done overall as an industry, and our industry track record has not been that stellar. With safety, scope, cost, schedule, and quality as guiding principles, our project managers today must address high expectations on every project. This paper examines some items that should be on today's project management checklist.

PROJECT ENGINEERING

Herbert Hoover, himself a mining engineer, said

> *Engineering is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege.*

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President Hoover then goes on to point out that

the great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them.... The engineer simply cannot deny he did it. If his works do not work, he is damned...

And so it is with those involved in the execution of major capital projects. While armed with advanced technological tools, the expectations placed on projects have never been higher. There have been many books written on how to do projects and the keys to project success, dissertations presented as to why projects fail, detailed audits performed on what went well and went wrong, and post-completion evaluations to determine if the projects have realized their operational and economic goals. Nonetheless, the scoreboard of recent projects in the area of mining and mineral processing is less than stellar. While there have been some truly spectacular engineering accomplishments, the metrics by which engineers view their work may be different than those used by investors to evaluate a project. This paper highlights some key aspects of project evaluations and feasibility studies that improve the likelihood of success and then identifies the five key areas upon which our project managers focus during project evaluation and execution.

PROJECT EVALUATIONS AND FEASIBILITY STUDIES

The competition for investment dollars, the impacts of Sarbanes-Oxley on the details and the process for proper disclosure, the perspectives of shareholders and the Securities & Exchange Commission (SEC), the watchful eye of the analysts following our industry, and the credibility required to access the financial markets all place more importance on good project management and project success. Our companies are all trying to meet the expectations of shareholders, regulators, analysts, investors, potential investors, and other stakeholders.

The SEC, for example, is operating under a clear mandate to improve disclosure requirements for mining companies. Before reserves for a greenfield project can be stated by a mining company, the SEC looks for a bankable feasibility study. Their perspective is that prefeasibility studies almost always underestimate actual capital cost. The SEC suggests that for small cap companies, only 10%–30% of the reserves based on prefeasibility studies are eventually developed. For larger companies, 20%–60% of projects based on prefeasibility studies are eventually developed. However, the SEC has indicated that 60%–90% of the projects based on feasibility studies are eventually developed.

The article in *Engineering Mining Journal* (January 2002) titled “How Have We Done?” (Chris Gypton, Senior Project Engineer, Hecla Mining Co.) is often referenced when capital efficiency and capital cost uncertainty are discussed. The article analyzes mining projects developed since 1980 and concludes that there is little doubt that the average feasibility study estimate is far less accurate than companies and bankers would like. The study concludes that actual projects overrun the feasibility estimates by an average of 22%. A full 20% of the projects overran by over 40%. The impact of a 20% overrun on a mining project can lower the internal rate of return by as much as 6 percentage points. These potential impacts are quite sobering.

It was interesting to note that there was no apparent correlation between overrunning the estimate and those who compiled it. Studies assembled in-house and those prepared by major consultants are equally likely to overrun. Upper-tier operators perform no better than the juniors. Neither size nor location appeared to influence the likelihood of an overrun.

There are several factors flagged that influence the quality of a feasibility study including

- Limited resources,
- Limited time to complete the study,
- Poorly understood site conditions,
- Inexperience of the contractor and/or the client, and
- Development time from completion of study through permitting and into construction.

One reason for lack of project success is that some projects with questionable economics advance to construction. Many projects advance from scoping to prefeasibility to feasibility to board approval to construction because those involved with the project become attached and project momentum can carry the champions of a project through weak risk assessments that lead to overly optimistic projections. Some of these risks can't be overcome even by the best project managers, engineering companies, and subsequent operators. Our message to our project managers emphasizes the need to work with the engineering service providers and project proponents to ensure a proper and formally documented risk assessment.

Among the more significant of project risks is scope creep. There comes a time in the project when the scope must be frozen. A major project is challenging enough even with a fixed scope of work. So herein lies an early conflict: the need for an accurate capital estimate and the need to limit the expense of human and financial capital required to evaluate a project to absolute certainty. There is a time for conceptual ideas to stop and for engineering to begin.

Before leaving the discussion on the feasibility study, one obvious point bears restating. There is no better time to build capital efficiency into a project than during the feasibility study. There is no better time to increase the probability of financial success. As you advance a project through detailed engineering and construction, your ability to influence project success diminishes progressively. As the project advances, changes to scope can only be made at a cost to other aspects of the project. Late in the project, changes can destroy a project budget.

It is important to set aggressive capital cost targets during the feasibility phase of a project. These targets can be based on industry-wide comparisons, operating experience, stretch goals, and application of new technologies. These targets serve as benchmarks for the project team to gauge progress. Too often we can reach the end of the study only to learn that the scope and resulting capital estimate do not support advancing the project. This could force a costly delay to re-work the scope and estimate, or worse, could contribute to abandonment of the project over factors that could have been mitigated. It should also be noted that a greater level of engineering review and risk assessment is needed when new technologies are being implemented to fully understand the potential impacts to project cost, schedule, and subsequent operation.

FIVE AREAS OF FOCUS

The five areas of focus that guide our project managers throughout the course of a project are Safety, Scope, Cost, Schedule, and Quality. Following is a brief discussion of the key factors by which we evaluate our project management effectiveness.

Safety

Good safety goes hand in hand with the project's cost and schedule. ***Safety is the leading indicator of the overall performance on a project.***

For Phelps Dodge, safety is a core value, and we believe safety on a project must be institutionalized in our project managers, in the project team, in our contractors, and in our service providers. You may be aware of our "Zero & Beyond" safety philosophy. The only acceptable safety metric is zero recordable incidents.

In order to achieve this clear objective, safety must become woven into the fabric of every employee and extend into the home and to activities outside of work. We therefore promote safety off the job, which is the "beyond" component in our Zero & Beyond process. We recognize that you cannot think "safety" only when on the job.

This same philosophy has to extend to the project and into the organization of any contractor working on the project. Safe working conditions and safe working behavior have to be an imperative. It is also an objective around which everyone can rally. It must become the mantra of the workforce.

Safety goes beyond ensuring a safe working environment on site. It goes beyond requiring compliance with the relevant safety rules and regulations that apply to the particular site. It goes beyond MSHA & OSHA. In goes beyond the contractor's safety program and performance. Regulatory requirements are the minimum standards against which we gauge our performance.

During the detailed engineering phase of a project, it is recommended that a formal hazard and operability (HAZOP) review take place. This is a step beyond a project audit, which might look at a variety of health, safety, environmental, and regulatory issues. A HAZOP review procedure will examine each process at a detailed level and systematically question every aspect to

- Establish how deviations from the design intent can arise,
- Evaluate and rank the associated risks, and
- Establish a managed process to address identified risks.

The HAZOP review team will, in a structured way, identify potential design issues. Many of their conclusions will be fairly obvious, such as a pump failure causing a loss of circulation in a cooling water facility. The process, however, encourages the team to consider less obvious ways in which the design could result in a problem. Phelps Dodge has utilized third-party and in-house HAZOP facilitators depending on the complexity of the process.

During the feasibility study, Phelps Dodge also applies the first phase of its Hazard Evaluation and Risk Assessment (HERA) program. The idea is to have a review, identify, and understand, even during this early stage of project engineering, both the execution and operation-phase hazards associated with the project. This review will initiate a formal process to control exposure and mitigate potential hazards during conceptual engineering. Eventually, at a later phase in the project, job safety analysis and standard operating procedures will be developed for each operational and maintenance task.

The HERA program advocates "consequence thinking" with regard to constructability and the potential impact of the proposed facilities on operations and maintenance. Consequence Thinking is a conscious process of taking the time to think through a task, identifying and controlling all energy sources, including individual behaviors so that injuries do not occur. We believe that Consequence Thinking needs to be part of our process, part of everything we do.

It is important to remember that hazards are equal to the sources of potentially harmful energy, and risks are equal to the frequency and extent of our exposure to the energy sources. So the three components of an injury are addressed in Consequence Thinking:

1. Identify the hazards,
2. Evaluate the risks, and
3. Take steps to reduce the risk.

One thing to bear in mind when analyzing risk: most fatalities appear to be found in the routine tasks with high-energy exposures.

Phelps Dodge believes that Consequence Thinking drives safe behaviors. We want all employees, including contractors, to think about the next 15 seconds. We teach hazard recognition so that employees will be able to identify hazardous energy (e.g., electrical exposure, chemical proximity, overhead obstructions, suspended loads, moving objects, and flammable materials). Thinking about the next 15 seconds will reinforce, for example, lock-out tag-out procedures, tying-off requirements, and use of proper personal, protective equipment.

Scope

The scope of a feasibility study has to be of sufficient detail, the engineering and construction criteria sufficiently defined, the completeness of the project sufficiently established, and the accuracy sufficiently tight that the study can be considered "bankable."

At some point in the feasibility study the project scope has to be frozen, and at some point in the construction, the stake has to be driven into the ground. There is often a misunderstanding of what constitutes a trend and what constitutes a variance. It is important to establish an understanding of these terms early in the project. Trends are costs that are either higher or lower than estimated, but nevertheless represent costs associated with items clearly in the scope of work and required to deliver the project as it was represented to the board of directors. Variances represent additions to or deletions from the scope of facilities and were not part of the project as originally approved.

Having said that, variances are often warranted and can be justified on a standalone basis if they enhance the value, operation, and/or safety of the project. These variances are often tied to future operating efficiencies.

At times, however, variances often develop as a result of a fundamental misunderstanding of contingency. Our view is that contingency represents projected costs that the project fully expects to incur. Contingency is an allowance for items that are known to exist but have not been detailed in the capital estimate. Contingency is not an allowance included in the estimate to cover additional scope items or discretionary expenditures. Contingency is not money at large for use by the project. Strict adherence to variance reporting and the approval process is absolutely essential to preserve the capital budget.

Cost

When I talk about costs, I am really talking about controls. It is an understatement to say that controls have to be in place to track incurred costs, committed costs, and forecast costs on a project. A discussion around cost control is probably a worthy stand-alone paper on its own.

The objective of project controls is to assure that detailed project scope, capital estimate, execution plan, accounting systems, and cost/schedule controls are established for the entire project at the outset. The timely implementation of adequate controls can make the difference between project success and project failure.

A project control system is a complete and comprehensive process during which all aspects of project execution are monitored and reported against the originally approved scope of work, budgeted costs, and project schedule. The project control system provides the basis for decisions whereby the project manager receives timely data from his controls team and then follows up with the necessary corrective action. Project controls are like many aspects of the project in that they require continuous cycles of planning, execution, and follow-up.

Project management is responsible for all project costs. Once approved, project expenditures cannot be made or allocated without project management approval, nor can changes be made without going through the proper management process for change orders and variances.

Let me make a few personal observations. We generally do a good job of recognizing how much money we have already spent. We do a pretty good job of recognizing commitments that have already been made. If projects have an Achilles' heel, it is in their inability to forecast expenses accurately. Some do a good job with this, but some are notoriously inaccurate. If there is one area upon which the controls manager should focus, it is on evaluating the work plan and the cost projections for that work plan. Then he must monitor progress to make sure it is consistent with the work plan. One aspect of the monitoring process is to ensure that the project controls group verifies all numbers used to measure the progress of the project. This can be such a key aspect of a project that independent third-party audits at critical junctures in a project should be considered. Early identification of any control problems is critical to ensure timely recovery.

The most sophisticated project control software is only as good as the cost control managers, whether they work for the contractor or the client. The importance of the dedication and diligence of these professionals can't be overstated. These are the people who raise the flags on issues that need to be addressed by the project managers.

And finally, while the project controls manager is an integral part of the project team reporting to the project manager, he must also have an independent line of reporting available to him outside of the project team to ensure all concerns can be advanced to resolution.

Schedule

Maintaining the project schedule is critical to a successful project. It will affect the cost of the project. It will affect the work plan. The first major indicator that a project is out of control is when reporting fails to take place. Schedule impacts will follow.

The project manager must ensure that all work is scheduled, completed on time, and accurately reported. This is facilitated through construction schedules with well defined, measurable milestones, construction audits, walk-through inspections, regular

review meetings, comparisons of actual progress to the plan, identification of any deviations to the plan, and follow-ups to corrective action. A strong project controls team can greatly assist in these efforts.

There is no substitute for meeting with the key project personnel to review in excruciating detail the status of each and every element of the project.

Quality

There are two groups that are going to look at the quality of a project with a critical eye: the project team and its customers, the future operators. While the project team is trying to satisfy many stakeholders, the operations team has to be at the top of the customer list. Documentation of QA/QC work is critical to a project and the project team's confidence in the work.

Quality begins with vendors and the provision for equipment that meets the standards defined in the specifications. Audits of procedures and frequent checks on suppliers' QA/QC programs are critical and can often highlight supplier issues. In addition, a well-defined, visible, and independent quality assurance program must be in place in the field. Clearly established procedures, documentation, and follow-up will discourage shortcuts by well-meaning contractors trying to make a schedule or budget.

In addition, operational checks made as part of the QA/QC program during commissioning and start-up, if properly documented and managed, will serve the operations and maintenance teams long after project turnover. Initial measurements of performance standards taken during the start-up will provide benchmarks to which later measurements can be compared to support predictive maintenance and reliability-centered maintenance programs.

SUMMARY

Most of the material presented above is not new to those of you involved in projects and project management. The key, of course, is discipline. I want to emphasize that organizations come to the project manager for a process, a process that if followed will result in success. My point is that while we provide a process, it is still the skilled and diligent project manager and qualified team that ensures the process is followed, that the key project metrics receive the appropriate focus, and that the client is ultimately pleased with the results.

Proper selection of the project management team is fundamental to the success of the project. This applies to both the owner and the contractor teams. It is important to note, however, that the project team, the owner, the various contractors, and other internal/external entities do not necessarily share the same goals. The key is to bring these interests together around project goals that can be shared by all. Some of the alignment can be structure in the contract where certain behaviors and performance can be prescriptive and even rewarded. Some alignment can be achieved by simply bringing the various interests together in a formal session to establish common project objectives.

A good project results when the project team accepts responsibility for the work product and does not abdicate the decisions and accountability to the contractor. Spectacular project failures have resulted when the client steps back and does not actively participate.

Within Phelps Dodge, our client is generally the host property that will inherit the project upon completion. Phelps Dodge stresses maximum client involvement, and the property will assign a point-of-contact as their representative on the project team. This operation's coordinator will ensure that their personnel are involved in all phases of the project. Their active participation not only establishes ownership but also ensures that the project reflects any site-specific requirements, operating philosophy, or preferential equipment specifications. From a project's point of view, the client's active participation is essential to ensure success.

Harry Parker (AMEC Inc.) offered some good advice that is applicable to project work: "Assume nothing...check everything...trust no one." I would add: document everything.

The following checklist supports the strategies I have already discussed:

- Develop detailed scopes for the project work and the facilities.
- Develop a detailed execution plan for the project.
- Empower a strong project manager.
- Select the "A" team with each key project management position staffed with a qualified individual.
- Establish a clear organizational structure.
- Set high standards and expectations for reporting on the status of the project.
- Implement proven project control systems and demonstrate that they are working properly as early as possible.
- Over-communicate on all key issues.
- Build a project team with common objectives and shared values.
- Develop a single point of contact for each key area of the project, especially at interfaces between the contractor and the client.
- Hold the appropriate managers responsible for the safety, scope, cost, schedule, and quality of the project.
- Plan the work and work the plan.

In closing, I would like to emphasize that a dedicated project team that is made up of responsible and accountable leaders is the most important ingredient in the recipe for success. To these engineers I take off my hat in acknowledgment of their accomplishments. As Herbert Hoover said:

> *No doubt as years go by people will forget which engineer did it, even if they ever knew...But the engineer looks back at the unending stream of goodness which flows from his successes with satisfactions that few professions may know. And the verdict of his fellow professionals is all the accolade he wants.*

Are You Really Using Your Information to Increase the Effectiveness of Assets and People?

Osvaldo A. Bascur* **and J. Pat Kennedy†**

Large metallurgical complexes have more data than a small city and much of it is "real time," changing rapidly as internal and external conditions evolve. As corporations buy and sell assets and reengineer their staff, the structures and tools that were used to understand these data are lost. The lack of an integrated approach makes the profitability of metallurgical plants lag behind that of other industries despite technical advances that have occurred in recent years. This results in significant deterioration in the ability to maintain a "smart" operation. The solution is to use the sophisticated new tools built for the Internet so as to leverage information in a familiar browser format that people can use and understand.

Combining real-time infrastructure with portal technology is becoming an accepted methodology. This paper introduces real-time portals and team sites to support decision making by workgroups which require both real-time and documentary information from manufacturing assets, vendors, head office and the Internet. Workers get insight from the overall process effectiveness index based on key variables such as losses due to plant availability, performance efficiency and rate of quality. Real-time portals and smart clients are part of any real-time performance management (RtPM) solution. Three case studies in large metallurgical complexes are presented.

PLANTS ARE YOUR STRATEGIC HANDICAP

Information technology is arguably one of the fastest moving technologies used by the mining/metallurgical industry. However, the business model for managing that

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technology often is fundamentally the same model that evolved from the mainframe era (Lorang 2002).

IT is by nature strategic; it creates possibilities that did not exist before. However, without innovative processes all you have accomplished is the automation of current bad processes and procedure.

The improper separation of systems between Enterprise Resource Planning (ERP) and the plant is a major problem with the buying and selling of assets. The pressures that are facing the plants are different. In addition to lower costs, they have to insure safe operation, meet regulatory requirements, and deal with a labor force that can be mobile in stressful times. One consultant once stated this succinctly—plants are a strategic handicap. The extraction of metals has become a global business. Many new forcing factors are present today which were unheard a couple of years ago. Plants must focus on plant operations—short-term gains in profitability can be achieved by increasing mining and metallurgical processing unit efficiency and reducing operating costs. Long-term gains can be achieved with continuous improvement—but you cannot improve what you cannot measure.

Metallurgical complexes are attempting to become better neighbors, increase productivity, improve customer service, and satisfy the regulators and compliance groups—all with fewer people and less costs. Plant information systems span the gap between management business objectives and the regulatory control level. Each business day many companies throw away a valuable corporate asset, their current and historical knowledge of the operation.

With IT projects, we should say that the winning strategy is to define the infrastructure that works with any project because we do not know what the winning strategy is at that point. This is not much different than the approaches taken for continuous improvement—putting a robust and reliable infrastructure that allows and encourages everyone to make small changes that eventually net a large change. The focus is managed by good metrics, not enforcement, and people are enabled by functional tools and collaboration, not by project schedule.

Not only should the project be strategic, it should contain something that gives it unique advantages and differentiates it from business as usual. The advantage that plant systems have is that they understand and utilize the concept of high fidelity, real time, events and historical information. Business systems have just discovered that they can measure these kinds of data, but industrial systems have being doing this for years. A greatly simplified model of a metallurgical enterprise or complex is shown in Figure 1. It shows the integration of the metal production from mine to products. Associated with the mining process, mineral beneficiation, metal extraction and production are reagents, energy, water, environmental and safety issues. At the same time information is generated at each step of these processes.

Figure 2 shows the typical systems that manage the real-time information. It shows large disconnect between people and systems. It presents just some of the systems that participate in the real-time applications including metallurgical laboratory data, maintenance, performance calculations, mining systems, pipeline systems, process control and business systems such as settlements, and reliability. Actual facilities can average 35–50 different systems, any one of which might be needed on a project.

The metallurgical laboratory systems usually contain at least a module to manage the lab, schedule lab resources such a sample collection, and support the analyzers. Sometimes they include specs, formulae, material data sheets, and much more. The mining system captures the ore movements, virtual signs of the mobile equipment and their

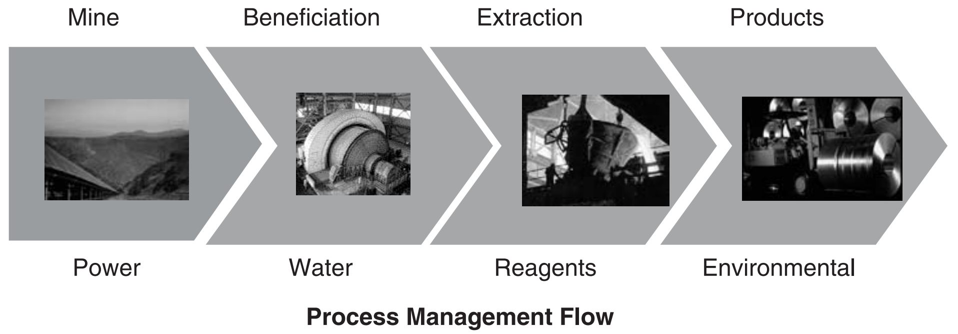

FIGURE 1 Integrated metallurgical processing

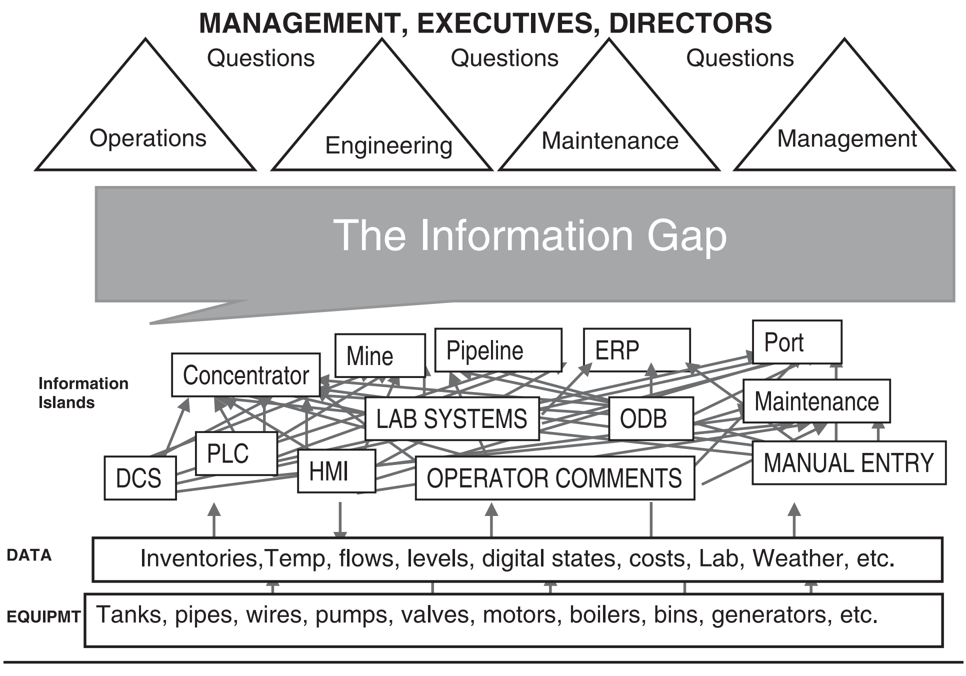

FIGURE 2 Typical array of systems in a metallurgical complex

position, and schedules the resources for moving the ore and hauling the material. The maintenance system will have work order, documentation, and personnel scheduling. The process control systems are so widely varying that we recommend a process data manager that interfaces to all different systems and presents them in a consistent manner to the integration layer. Connected to these at the corporate level is the ERP system that is responsible to account for the plant and provide the resources the facilities need to operate efficiently (e.g., fuel, human resources, contracts, settlements).

There are two problems that have generally not been solved by current systems, the distribution of the information to those that need it and the combination of the information in the proper analysis environment. The Intranet addresses both of these. The business systems sometimes replicate a small fraction of the low resolution data, but this will not be enough to make operational changes that reflect the business needs except on a long-term basis (weeks, months). When assets are purchased or sold or the plants are modernized, and information systems are cleaved or merged, it becomes much worse. Daily, opportunities are lost because information cannot be quickly collected, validated, analyzed and presented.

Operating and maintenance problems can go undetected and uncorrected for months. When a process engineer requires the information to create a report, he needs to get data from the DCS and from the laboratory systems. Maintenance personnel rely on averages to make decisions about the process equipment. Managers get reports, which are made by others. The underlying data and navigational methods to access them are not available to decision-makers in order for them to look for root causes and identify opportunities. Vertical applications such as maintenance systems, accounting systems, and planning systems are all isolated from each other. Each application contains a specialized database, which requires integration by others. This all culminates with a morning meeting that starts with the "passing of the scrolls."

Any time in a meeting spent exchanging information is a waste of everyone's time and a symptom of inadequate distribution of information and analysis tools.

Disparate plant systems are a major impediment to becoming more responsive. The money and effort to change these systems is great and the people that own them are not very open to the changes needed. Opportunities are lost and a company will lag its competitors when they find themselves unable to change manufacturing to meet the customers' challenges. To improve, the plant systems must accomplish several tasks:

- Receive communication from the business systems as to what they must produce and what raw materials they will receive;
- Communicate to the business the capabilities, inventory level, production rate targets;
- Support for operations management so that they can implement the advanced strategies;
- Support for staff functions including laboratory, personnel, maintenance, quality, safety, and environmental.

Today most manufacturing systems are assembled from packages that deliver support for tasks that may or may not be related to roles they have chosen for their people (process models, reconciliation, planning, scheduling, advanced controls, batch controls, tank farms, blending, environmental, training, safety). The problems of conversion, porting and reconstruction of the applications from the legacy systems to a modern distributed environment are all consuming, and the purpose of better integration, which is better company operation, is lost.

This paper highlights current information technologies that are being applied in the development of enhanced dynamic performance management systems and integrated workflow systems.

MODERN REAL-TIME PERFORMANCE MANAGEMENT (RtPM) APPROACH

Without clear vision even new systems may not address the dynamically changing roles of the people in the company. Without a reasonable structure or development environment, there is no evolution of these systems. All business processes and the software that supports them must incorporate these continuous improvement capabilities.

Users vary from the power user on the LAN that can tailor his/her environment according to his/her role, skills, responsibilities, and accountability in the plant system, to the occasional user that simply looks at the displays of others. Why does anyone have to configure the systems themselves? Why aren't there packages to do this? No one knows the plant, raw materials, environmental and safety regulations and other conditions like the people on the floor that work for the company already. If these become projects, ideas are very difficult and expensive to transfer from one person to another so it will not get done and again the system dies. The other advantage of enabling the user is that the pleasure of watching one's own implementations succeed encourages more action.

The function of the Real-Time Performance Management (RtPM) infrastructure is to support the continuous improvements that create profits. This is quite different than Enterprise Performance Management which is also targeted at continuous improvement of margins but is driven from transactions instead of real-time events.

The business drivers for performance management are compelling. Among them:

- Collaboration throughout the extended enterprise, including global resources, suppliers and customers
- Empowering individuals to make profit contributing decisions at all levels of the organization
- Closing the loop between active planning and goal setting, and actual execution in real time
- Bridging centralized and decentralized organization structures.

The technology that makes this practical is Web Services—the self-describing elements of a Web application that can present the capabilities to anyone while hiding the complexities of the underlying application. The key is that Web Services are now universally accepted by operating system software suppliers.

RtPM is a real-time portal and a platform for software applications that gathers and transforms real time and enterprise data and events. Through a series of contextual and analytical tools, it presents timely information to individuals to make decisions (Kennedy 2003).

With the traditional PIMS, information is gathered into databases and disseminated as reports and on-line inquiries to all requesters, and the system's responsibilities end. This system is passive; it is not designed **for action**. RtPM allows users to apply their knowledge and expertise to continuously improve performance via direct interaction (e.g., looking for a problem with a trend) or composite applications such as asset management, real-time margin calculation, energy management, inventory and mass balancing, outage scheduling or environmental reporting. RtPM encourages people to take reasoning based actions. This is not just displaying process data, it is everyone in the complex working together. It combines data from the floor, business systems, and external systems in a pleasant presentation. It connects to the tools on the desktop to analyze and make discoveries about the plant and business processes and, most importantly, to implement his/her findings.

Counter to projects that focus on a single task at a single time, RtPM focuses on making innovation easy and pleasant. An interesting example of this is the case study of Codelco, the large Chilean copper company (Rojas and Valenzuela 1998, Romero 2000; Gareca et al. 2001). By taking the infrastructure costs out of a project and creating a robust, maintainable environment that does not take programmers or consultants to implement, most users will find that there are many opportunities for improvement. Codelco discovered this before it was even named and the Japanese practiced it but did not build the IT Infrastructure to support it. The Kaisen concept was successful using only psychology and groups, but many of the tasks they identified are much better performed by automation. The same concept is embedded in the safety laws such as OSHA PSM, FAA NTSB, or NRC).

The benefits of enabling your own workers cannot be overemphasized. One key to the benefits of RtPM is that there are many profitable small projects so the tasks are resilient to failure and easily allow change as the conditions facing the industry changes.

Identifying performance measures consistent with the plant vision and business objectives is a prerequisite to optimization. Significant profit improvement is possible once the key performance measures by business area are defined. These areas include mine production, raw materials preparation, concentrator, hydrometallurgical plant, smelter, refinery, tailings, distribution, environmental, safety.

The main aggregation of information is in the form of Key Performance Indicators (KPIs), which are used as a measure of overall performance. When those KPIs embody real-time manufacturing events and data, individuals from line operations, supervisors, plants managers and executives can collaborate to evaluate the actual performance either by actions or additional programs. This is the true power of continuous improvements.

The portal strategy allows business managers to participate in the evaluation of the plant KPIs via the Enterprise Portal, while operations personnel evaluate them through the Operational Portal. Figure 3 shows the RtPortal for operations. Information is presented based on their roles and adapted by their functions. The alerts are generated and the whole team is informed. The key player will find a resolution. Figure 3 is based on the RtPortal running under the Microsoft Sharepoint technology. As such, the commonalities of the general information technology are preserved adding the new communications, messaging and workflow technologies embedded in the new Windows Office 2003 technology. An important aspect of this technology is that people can design and adjust its environment to meet their role and job functions.

As such optimization is achieved and sustained by

1. Providing performers with consistent, accurate data and performance indices computed from plant mass balances, plant energy balances and corrected flow rates for temperature, pressure
2. Displaying key efficiencies for plant personnel to raise their awareness of overall plant performance including quality, production, cost, energy, maintenance, safety and environmental
3. Evaluating and displaying plant profitability to provide a real-time objective to be maximized
4. Calculating an integrated or plantwide cost penalty of key plant parameters being at non-optional values to help people make decisions
5. Monitoring major equipment to improve maintenance planning and reduce plant upsets, thus enhancing plant availability.

FIGURE 3 RtPortal: Integrated information using Web parts and asset alert details

Other RtPM opportunities throughout metallurgical complexes are as follows:

Operations

- Monitor process in real time to identify and correct operational, safety, and equipment problems before they become serious.
- Continuously improve the reliability of a manufacturing process.
- Identify and correct bottlenecks.
- Avoid upsets.
- Manage energy and water usage.
- Track waste.
- Minimize Metal losses in burden, tails or slags.

Quality

- Analyze real-time trends and history to determine the effects of variations in process parameters on key quality variables from feed to product.
- Produce greater consistency across all shifts at all plant locations.
- Maintain SPC control limits for any parameters.
- Manage quality from mine to products.
- Identify relationship between cutoff grade, recovery and financial transactions.

Operating Costs

- Reduce operating costs by understanding mine/mill/smelter/refinery interactions.
- Manage overall power consumption.
- Manage overall water consumption.
- Manage overall reagent consumption.

Productivity

- Optimize assets and improve equipment effectiveness.
- Monitor and report marginal economics.
- Share financial information and effect with workers.

Effectiveness

- Reduce equipment downtime.
- Improve recovery, yield.
- Monitor effect of changes.
- Cycle time.
- Agility
- Collaboration
- Empowerment

Asset Management

- Keep track of equipment utilization.
- Provide information to maintenance, management and operations.
- Improve collaboration between central and local teams.
- Track abnormal operation.

DATA ANALYSIS: BOTTOM LINE, YIELDS AND INVENTORY MANAGEMENT

One of the biggest challenges to process plant management is the accumulation of accurate information on process operations. This information is necessary for any analysis and decision-making within the plant and enterprise. Therefore, there is a requirement for meaningful, accurate and consistent data.

Material balances calculated from data measured at various locations around process units, tanks inventories, stockpiles, silos, bins, and assays are useful for many purposes, such as yield accounting, on-line control, and process optimization (catalyst selections, reagent schemes, liner replacements, water management, utilities management). To achieve material balances, gross errors or anomalies in the production data must first be classified, detected, and the source of the data examined.

Often, it is possible to calculate material balances by several independent procedures when excess measurement information, i.e., redundant data, is available. Clearly, if the data were collected without measurement errors (a theoretical condition never found in practice) all material balances calculated from redundant data would be in agreement. The real situation is that errors exist in practical measurements, so that the results of material balances determined from available optional procedures differ. Consequently, best-fit computational procedures to adjust the material balances by taking measurement errors into account can be implemented as suggested by Bascur and Soudek (2001).

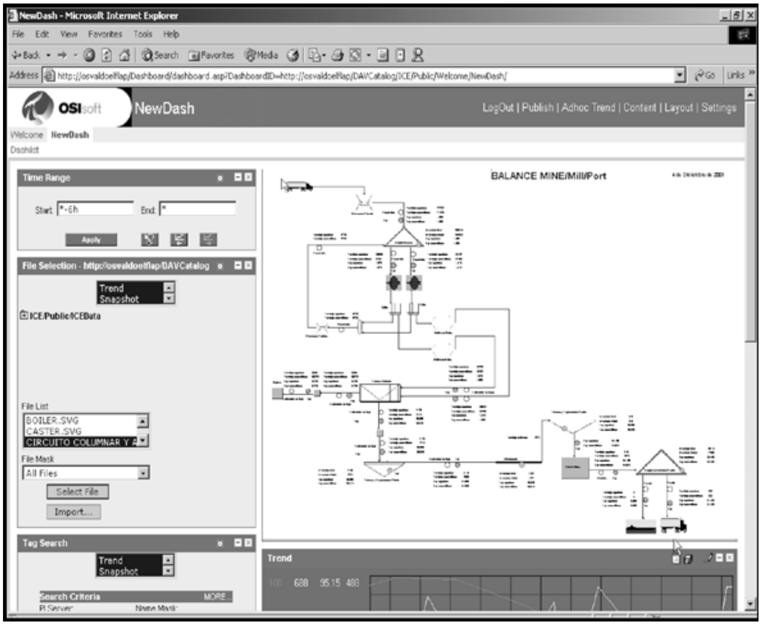

FIGURE 4 Web browser showing real-time performance indicators such as yields and inventories

In this case, the application framework is used to develop a process flow diagram connecting flow meters, tank inventories, stockpiles and composition analysis for the defined streams. A plug-in for data reconciliation and gross error is used to perform the calculations.

The PI Advanced Calculation Engine assists in organizing and formulating the analysis requirements. A process flow modeler is used to build the plant topology connecting units, flow and composition measurements, inventories and transactions. Once the process topology is defined, the Sigmafine plug-in can be used to reconcile the data from inventories, flows, and compositions. New advances in technology enable it to perform metallurgical balances of integrated industrial plants. As such, mine, concentrator, smelter, refineries and special treatment plants can be solved simultaneously to track metal values. The metal losses in tails, slag, and dumps can be calculated.

Figure 4 shows the results in a Web environment for access by management, personnel and external resources. The RtPortal enables anyone with a browser and a security password to access the information in real time. These mine/mill/port metallurgical balances are performed interactively by process, accounting and metallurgical personnel. In these applications considerable conventional errors have been detected saving metal losses and optimizing the metal recovery process.

The real-time information will access the associated variables during the period of time when this ore type was processed. Analysis of the metallurgical performance can be performed linking the grade/recovery with the grinding/blast strategies in a mineral processing plant. Real time–based costing emerges as a reporting exercise when the proper application framework for real-time information management is used. This integrated

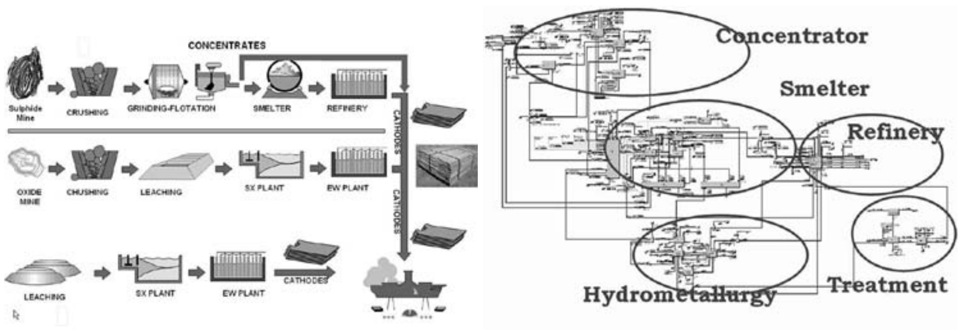

FIGURE 5 Typical Integrated metallurgical complex analysis using Sigmafine

approach enables collaboration between operations, engineering, accounting and management to drive the organization's bottom line according to their business strategy. At the same time personnel can look for opportunities using alternative processing methods and strategies (grinding efficiency, reagents, and blasting methods) to adapt to the changes in ore type to produce the least-cost concentrates.

Figure 5 shows a typical integrated metallurgical complex. Several plants are integrated from the mine, concentrator, smelter, refineries and other treatment facilities. The data analysis tool is used to validate the set of inventories, flows, compositions and transactions. Gross errors are identified. These events require the collaboration of process engineers, accountants and plant managers to identify the sources of errors or correct operational problems. Recoveries and grades are obtained. Metal losses are calculated based on the set of data provided. It is interesting to note that for this to work collaboration between accountants, process engineers, laboratory measurement and plant management is the key. The real-time performance management infrastructure supports this type of activity for the application of data reconciliation technology. Same is required for conditioned base monitoring. The people integration with their system was described by Bascur and Kennedy (1996, 2002).

PROCESS ANALYSIS, TROUBLESHOOTING AND FAULT ANALYSIS AND DETECTION

The most important step in transforming data into actionable information is to add context to the set. Integration of sensors data, laboratory, business plans, customer specifications, process and equipment events are vital. The most common standard is the S88 model.

The operational data structure for successful integration of production, process, quality and equipment health data can be aggregated by events for any process unit, its product/feed, for any time interval. A typical data structure contemplates using the following modules:

- Process operating conditions events,
- Operator manual data entries and quality data,
- Operator comments,

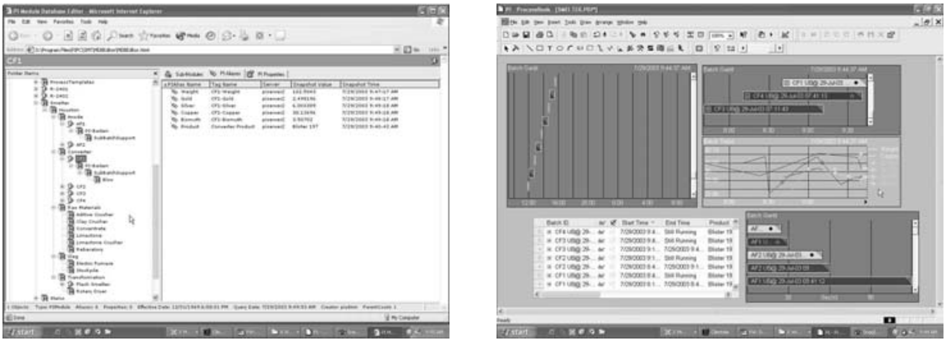

FIGURE 6 Real-time hierarchical module database and Gantt events viewer for a copper smelter

- Events from equipment or DCS systems, and
- All process variables and sensors.

Figure 6 shows a hierarchical plant topology of an integrated metallurgical complex. All key modules capture the events and dynamics of the transformation processes and movements. All heats, blows, casts, coils for a certain period can be inspected or a special selection by product quality or work order can be achieved. The process operating events for a typical Electric Arc Furnace are charging, melting scrap, feeding, super heating and tapping. For each of these operating states aggregation is possible for all the information for all sensors, manual entries, operator comments, equipment events, process variables and to correlate with quality results. Once the information is stored in such hierarchical manner, process data mining is simplified.

Figure 6, right side, shows Gantt charts for selected units of the metallurgical complex. The real-time events are showing and the interactions between the units are shown in real time. Once the information is available by events, patterns can be generated for detailed analysis, feature extraction for fault detection and diagnosis.

FROM MAINTENANCE REPAIRS TO OPERATIONAL FAILURE CULTURE

As the performance of the belt conveyors, crushers, furnaces, ladles, roller mills, pumps, compressors, thickeners, and other processing equipment deteriorates over time, equipment efficiency decreases, power consumption goes up, throughput is reduced and operating costs rise. Process and equipment performance event monitoring using desktop computers and remote access via the Internet offers an effective way to offset that toll.

Condition-based monitoring has been decoupled in six different patterns (Moubray 1997). Studies revealed that 68% of all failures were attributed to pattern F, while only 5% of the failures were attributed to pattern B. Pattern F is defined as at the start, high rate of failure and then consistent operation with very slow increase of conditional based failure. Pattern B is defined as at the start, stable, followed by continued stability, then a wear-out period. Moubray feels this study is substantial enough to translate across industries.

Djuric (2002) has shown that a new failure paradigm can be used for condition-based equipment monitoring. Based on the asset condition curve (or equipment degradation in time), he defines several stages. A failure condition starts early in the curve.

Between this early start and the old definition (equipment broken), a time interval between **potential failure and functionally failed** (P-F interval) is defined. The new definition of failure is based on equipment not performing the intended function.

The company wanted to change their maintenance culture from Equipment repair to Asset Management without increasing maintenance costs. Using the PI system, they implemented condition-based equipment monitoring. They changed their failure paradigm to an interval of potential failure and functionally failed (equipment not performing has intended function). They have changed from 70% total maintenance hours and 30% proactive maintenance to 20% reactive maintenance and 80% proactive maintenance. Average equipment availability has gone from 78% available and 22% unavailable to 91% available and 9% unavailable.

Figure 7 shows their graphical presentation of how the modgun nozzle to the tap hole face fit has deteriorated into an alert. They have gone from scattered knowledge to business process and practices with a consistent organized way to capture and use information and knowledge.

Inconsistent actions	→	Actionable knowledge: Easy access to knowledge repository
Maintenance work	→	Consistent action: The right work at the right time

In Blast Furnace #4, they have extended the furnace campaign from 8 years to 15 years, resulting in a savings of $1 MM per year, or $7 MM for 7 years. For Blast Furnace #3 they have extended the campaign from 8 years to 20 years, resulting in a savings of $1 MM per year, which results in a savings of $12 MM for 12 years. Their projected savings are $19 MM just for this example.

The PI system has enabled them to develop many small projects within their iron and steel industrial complex such a caster breakout program, energy management, and others.

CONNECTIVITY TO ERP SYSTEMS

The RLINK gateway to ERP systems reduces enterprise integration costs. The result is a standard ERP configuration that enables process engineers and management to leverage production information. RLINK supports Microsoft and ERP vendors (SAP, MRO, J.D. Edwards) standards to provide organizations with all the information needed to make profitable business decisions:

- Asset Efficiency—Operating to capacity and maximizing equipment uptime with timely, condition-based maintenance using operating hours, number of starts, and alarms (e.g., temperature, pressure, vibration) to trigger maintenance.
- Increase Profits—Plant control systems don't have access to data required to optimize profits like material costs, energy costs, market demand and prices for finished products.
- Enhance the level of coordination and collaboration between manufacturing, maintenance and logistics business functions.
- Analyze tradeoffs to satisfy business objectives of reducing operational costs and inventory, improving delivery reliability and response time, and service to the customer.

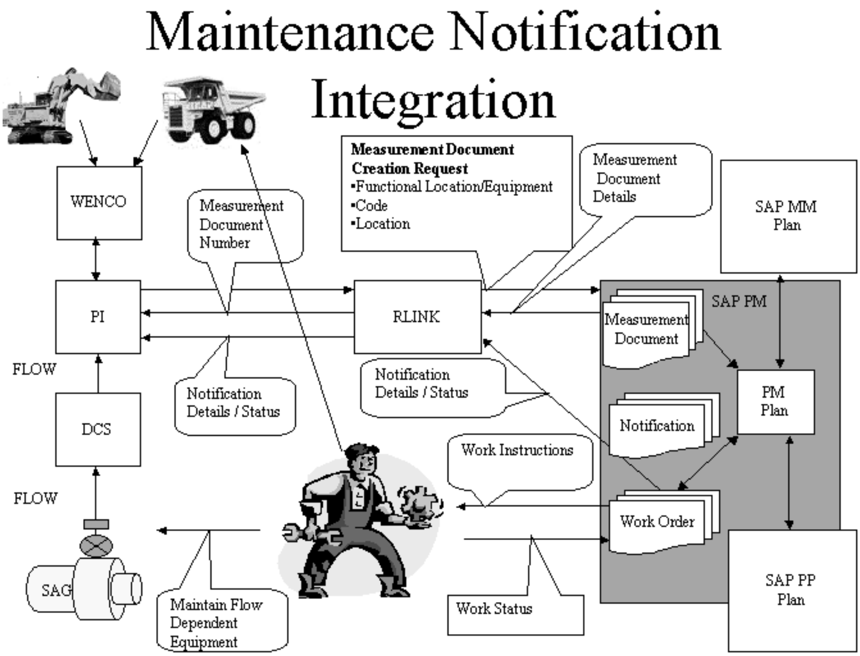

FIGURE 7 Mine-mill real-time information management integration and maintenance notification

- Cycle Time—Reduce time from product order placement to customer delivery.
- Available-To-Promise—Provide reliable delivery date to customer (i.e., when order is taken) based on real-time view of finished goods inventory, production plan, raw materials, etc.
- Reduce magnitude and complexity of production management reporting.
- Overcome problems associated with manual entry: Data entry is slow and error prone, manual calculations are often required, limited volume of data that can be handled.

For example, R/3 must be notified when problems occur in manufacturing (Stengl and Ematinger 2001). Without a real-time connection, R/3 may only recognize a problem when it's too late (i.e., if product is not shipping). Reacting to problems is inefficient, so critical plant events must be escalated to R/3. As companies move to an E-Business environment integrating suppliers and customers over the web, greater demands will be placed on internal coordination between manufacturing and sales. RLINK enables companies to react to unplanned manufacturing events. Therefore, companies will be required to provide a more timely and accurate view of manufacturing to the ERP system to compete in the E-Business world.

REAL-TIME INFORMATION MANAGEMENT INFRASTRUCTURE CASE STUDIES

There are many examples where the requirements for process, laboratory, maintenance and business systems have driven the decision for data integration to empower the work force. Many simple projects are generated with high return on investment rather than a few isolated traditional projects. These were selected because of their objective to reduce maintenance costs and increase overall process effectiveness (Luyt 2002, Llao 2001). In all cases, the customers integrated to their current maintenance system with the PI system (i.e., SAP PM, Advantis, Maximo, MIMS). These case studies reported integrating the mining, concentrator, port and shipping facilities.

Situation 1: Mine/Mill/Pipeline/Port Mineral Processing Facility

Capabilities needed:

- Integration to all existing mining, DCS, MMIs, and PLCs and ERP systems
- Personnel should have data for fast process troubleshooting and root cause detection
- Remote view of key performance indices
- Access to process data by all personnel (operations, maintenance, engineers, planning, and managers)
- Easy access to historical information using MS Office.

Results:

- RLINK PM has been operating since July 2001. They have installed RLINK PM to integrate these systems to pass equipment maintenance parameters between the new business system, the mine and the processing plants. Figure 7 shows the interconnections. This integration provides the ability to generate maintenance notifications from any of these systems manually or automatically.

Currently, 180 pieces of equipment from the mine and 500 pieces of equipment from the ore processing plant are configured in RLINK. Notifications are created in PM based on asset hours, failure codes, and GPS positions. In additional, RLINK provides valuable maintenance parameters for equipment failure assessment and maintenance planning. This was critical since maintenance is normally 30% of the annual cost in an asset-intensive industry like mining. Any percentage savings has significant economic implications.

Situation 3: Large Copper/Gold Metallurgical Operation

Capabilities needed:

- Integration of mine system, concentrator DCS/PLCs, maintenance and production systems using MIMS, MUMS and pipeline system.
- Fast-track implementation of performance monitoring and analysis
- Real-time information access of mine, concentrator, pipeline at the desktop for all functions

Results:

- Increased nominal production rates by more than 20%
- Increased equipment availability
- Enabled mine/mill optimization
- Cost management. Tracking grinding mill relining and ball consumption
- No need for specialized programming to generate real-time graphical displays or reports
- Implemented a real-time plantwide water management
- Implemented a real-time reagent inventory and purchasing system. Automatic purchase order and shipments
- Implemented safety, fire and security systems.

Their main objectives were the integration between personnel functions for collaboration and the integration of their mining, DCS, production and maintenance systems for real-time decision-making and debottlenecking of the mine/mill operations. They use their system to identify and to eliminate constraints within the entire system: equipment availability, process, systems and inventory management.

An event management system was implemented to identify the downtime causes, and equipment and process constraints. They have defined the following variables:

1. Uncontrolled variables: rock type and weather factors, which affect energy availability
2. Controlled variables: stockpile management, water availability, and inadequate operation of the equipment

Their continuous improvement objectives include:

1. Minimize bottlenecks within the integrated mill.
2. Generate shift, weekly and monthly variable costs/production control and variance tracking.
3. Adjust predictive maintenance and the relation with steel/treatment for increases overall equipment availability.

CONCLUSION

Integration of metallurgical complexes is a reality. Companies are using integrated information architecture as a strategic investment for enabling agile operations. Making profitable, intelligent business decisions is a complex process, made easier through RtPM strategy. A robust environment provides real-time, historical process/equipment information and business information for all functions to collaborate.

Using their Web browsers' knowledge, workers can remotely locate the data and advize operations on the next step to take.

The results can be summarized as follows: Improved quality and speed of plant diagnosis, optimizing plant overall process effectiveness (production, quality, costs, availability, environmental and safety), extended plant availability, improved production and regulatory information.

Process knowledge must be put in a form that it is easy or intuitive to use. If systems are installed that do not recognize that people have to use them, then these are new legacy systems whether a mainframe or a PC running Windows XP. This is all a brave new world. We hear names like Web servers, SOAP, HTML, XML, Structured Storage, Monikers, ActiveX Controls, and Uniform Data Transfer. These words sound foreign but are the basics of the new compound architecture. However, we are all embracing these new technologies.

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Knowledge Management: Does the Right Hand Know that the Left Hand Is Mining?

Charles A. Weinstein*

INTRODUCTION

As a set of management practices, "Knowledge Management" (KM) has disappointed many of its early advocates. The core notion behind KM can be summed up in the oft-quoted adage, "If we only knew what we know." KM describes a set of tools, practices, and approaches for using data, information, and expertise—knowledge—resident in an organization to improve the performance of that organization. The idea was incubated, hatched, and grew among some the largest and most successful companies in the world. Some of these companies created "Chief Knowledge Officers." Many more collectively invested billions in a huge range of KM efforts, all designed to use their organizations' information and expertise to innovate, improve margins, sell, or accomplish any of a myriad of sound business goals. Some KM efforts were successful, and many were not.† Today, it is indisputably the case that KM as a named set of practices has fallen out of favor.

Why, then, should KM be discussed at a conference on "Things that Actually Work" for plant operators? Because, in many instances, KM has actually worked. The practices that represent KM *done right* offer significant opportunities for plant operators to achieve real gains, especially in times of resource constraints and in the face of ever-increasing technical and commercial goals. The KM fad is all but over. The KM benefits continue to accrue to those who have applied the lessons learned from that fad, and implemented sound

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† Fair disclosure: I am not unbiased with respect to the potential impact of KM. Teltech has been a pioneer and leader in KM, both as a practitioner and as a leading consultant to other organizations.

efforts aimed at improving the performance of any number of processes in their organizations. The aim of this paper is to explore how to use KM to achieve just these goals.

This paper is divided into two sections. The first, Knowledge Management: Lessons Learned, begins with an overview of knowledge management and discussion of why it has sometimes gone wrong (and, in turn, what factors tend to promote success). This discussion relies upon Teltech's research report, *How to Find Value in Knowledge Management*, published in 1998, and upon our ongoing work since its publication with a wide range of companies. The second section, Applying these Lessons to Plant Operations, aims to accomplish precisely what the title suggests: to present applicable lessons for using what works in knowledge management to improve and optimize plant operations. This paper is based upon our research and experience. It is likely less scientific in its approach (and almost certainly less technical in its orientation) than others offered for this conference and publication. It is my hope that readers nevertheless find it thought-provoking and useful.

KNOWLEDGE MANAGEMENT: LESSONS LEARNED

If the concept of KM is unclear to many people, it may also be the case that the concept of knowledge itself, in this context, also requires further definition. Let us define knowledge, for the purpose of this discussion, as **information and expertise that is capable of enabling action**. Such actions include business decisions of all sorts, process changes or execution, or product innovations or developments. KM, then, is a set of tools and practices for more effectively capturing, deploying, and re-using knowledge to help organizations act more effectively.

Can Knowledge Be Managed?

The next concept that sometimes raises questions is the notion of managing knowledge. "We manage people: individuals, teams, organizations," some people comment, "we don't manage knowledge." In fact, companies today manage all kinds of strategic assets, from cash to capital equipment. Knowledge—in particular the expertise that distinguishes organizations and differentiates them in terms of capabilities and competencies—is clearly a critical, strategic, if intangible, asset. As such, better practices for managing that asset: for conserving and growing knowledge, and for deploying it to maximum advantage, represent a significant opportunity to impact business performance.*

To better manage this strategic asset, we divide knowledge along two axes, between "Internal" and "External," and between "Tacit " and "Explicit." Knowledge is either internal to an organization (i.e., originating and primarily applied within the organization), or it is external to that organization, brought in from outside (e.g., citing a newspaper article or bringing in an external consultant). Explicit knowledge exists in documents and data sets, written down or recorded in a way that can be stored on

* A good deal has been written about assessing and understanding knowledge as an intangible asset, ranging from the somewhat arcane but interesting work on the "invisible balance sheet" of knowledge and intangible assets by Karl-Erick Sveiby, to the much more practical works of Thomas Davenport and others. Davenport's early book, *Information Ecology* (Davenport 1997) is a particularly good discussion of knowledge as an asset to be grown and nurtured within an organization.

	Internal	External
Tacit	Knowledgeable, experienced people inside the organization	Domain experts (technical, industry, etc.) outside the organization
Explicit	Data, documents, reports, research findings, and other written information within organization	Journals, articles, research reports, databases, and other resources outside the organization

FIGURE 1 Examples of each knowledge type

paper or electronically. Tacit knowledge, in turn, is the learning, know-how, and experience that resides within people. Tools and practices must be tailored for each kind of knowledge, as reflected in Figure 1.

Knowledge Management Efforts

Understanding knowledge is necessary, but not sufficient, for effective knowledge management. Using that framework, it is then important to understand what can be done to improve the acquisition, preservation, distribution, and effective use of knowledge of all sorts. In general, knowledge management efforts deploy **information technology** to better manage **information content or expertise**, and to enable and promote **better knowledge sharing practices** within a **defined community**. These factors—technology, content, and people—represent the critical levers for knowledge management success. These factors are deployed in specific interventions: projects or applications designed to make better use of knowledge.

Knowledge management has been pursued primarily as projects or discrete applications, rather than as a diffuse "way of doing business." This approach is not universal; a few organizations have sought to imbed knowledge management practices in more diffuse ways across their organizations.* Teltech's 1998 research examined 93 applications of knowledge management in 83 companies. The study crossed industries, with manufacturing and high-technology factoring prominently in the sample with 25% and 20% of applications falling into these categories, respectively. Other categories and their representations:

* The American Productivity and Quality Center (APQC) has collected and written on case studies involving these sorts of organizations, including Buckman Laboratories; founder Robert H. Buckman has been for years a vocal advocate of this approach. APQC also offers a wide range of services and publications related to knowledge management.

- Professional Services (15%)
- Consumer Goods (10%)
- Financial Services (10%)
- Aerospace (5%)
- Healthcare (5%)
- Utilities (5%)
- Other (5%)

All of these projects were pragmatic efforts to improve the way that knowledge was used and produced tangible creations that could be analyzed.

Projects aimed to achieve one or more of the following business purposes:

- Revenue Generation (45%)
- Cost Containment (35%)
- Quality or Customer Service Improvements (16%)
- Other (4%); (Teltech 6)

Project success was measured by participants' and stakeholders' statements of the business impact of each project or initiative. This impact was determined to be high (40% of projects), medium (35%), or low (25%). (Teltech 21)

Why KM Fails

The research comprising *How to Find Value in Knowledge Management* is now dated, but much of it remains instructive today; confirmed by our practice and those of other knowledge management practitioners in the years since the study was published. Interestingly, perhaps the most efficient way to learn from this research is to focus not on the successful projects, but on those which failed to achieve impact. While projects succeeded for many important reasons, the 25% of projects that delivered low impact to their respective organizations exhibited a few common factors, all of which can be avoided.

These "failure factors" were not especially surprising. Initiatives judged to be failures by participants and stakeholders generally exhibited one or more of the following characteristics:

- Lacking well-defined business objectives
- Lacking a strong advocate or champion within the targeted organization
- Resulting systems were confusing or difficult to navigate
- Behavioral and organizational change measures missing or inadequate
- Insufficient resources committed
- Difficult or impossible to measure results.

Based upon these criteria, many projects were doomed before they began.

More positively, these "failure factors" really provide a checklist for critical success factors. Chief among the lessons learned was the need for a clear business objective. Planned projects must exhibit a clear path toward achieving benefits significant to the organization. Successful projects teams must also develop means for measuring project success and apply the discipline to carry forward these measurement programs. Factors such as executive sponsorship (itself dependent upon the need for measurable business

benefit) and a sustained commitment to promote behavioral and cultural change in support of the KM effort, are likewise critical success factors.

Selecting the Right KM Project

So, if clear objectives and measurable outcomes can be defined, and sustained organizational commitment secured, the next logical step is to determine what specifically ought to be done. Like knowledge itself, KM efforts can be divided into types, in this case based upon the kind of intervention sought. The Teltech study considered the following types of knowledge management projects:

- *Leveraging Expertise:* Using tools and practices to find experts and connect people to people.
- *Best Practices:* Means of collecting and sharing what works best across an organization.
- *Project Team Collaboration:* Using tools to promote document sharing and communication across geographic or temporal boundaries to promote more effective teamwork on sustained teams.
- *Product/Service Offerings:* Some organizations turned KM into revenue-generating offerings.
- *External Information Centers:* Electronic portals and collections of resources from outside an organization.
- *Comprehensive Knowledge Centers:* Bringing together multiple knowledge types and resources in a single, enterprise-wide application.

In practice, many KM applications are combinations or hybrids of these types.

Finally, KM is applied to multiple communities and business functions, from product and technology development through sales and finance. This clarity of purpose is closely linked to the project success: too often, failures were not adequately targeted at solving specific problems or achieving specific gains, and perhaps the best way to maintain that proper focus is to deploy KM in support of specific functions. Perhaps the most successful applications we have helped clients develop were highly focused: helping IT consultants in the field find others with similar skills, or sharing documents and learning across numerous product development teams to prevent re-work. Some of these applications have expanded to include other purposes, while others have remained in their original "sweet spot."

The Teltech study recognized that successful KM was generally targeted at specific processes or groups. Correlating what kinds of KM efforts tended to work for different processes or functional areas reveals very applicable insights. The results of that analysis, summarized in Figure 2, reveal several clear areas of opportunity, and some where particular kinds of KM seem less likely to succeed.* (Teltech 51)

It is not surprising that production functions—operations such as manufacturing and logistics—benefit from more effective sharing of best practices. Production environments are practical places, where pragmatic innovation and process controls are each applied

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* The analysis was based upon the studied sample; the absence of an application type for a given function does not mean that such an effort has not been successful elsewhere. Nevertheless, the breakdown is instructive of the kinds of efforts that work to improve different processes or functions.

Relative Frequency of Successful Knowledge Management Applications by Functional/Process Area and Business Objectives						
Purpose / Functional / Process Area	Leverage Expertise	Leverage Best Practices	Project Team Collaboration	Offer a Product/ Service	Make External Information Available	Provide Enterprise-Wide Information
Research Projects	xxx	xx	xxxxx		xxx	x
Customer service	xx	xxxx	xx	x		x
"Production"	xx	xxxxx	xxx			x
Patent portfolio management	x	x			xx	x
Project management	xxxx		x			x
Sales process		xx	x	xxx	xxx	x
Competitive intelligence/ strategic planning		x	x		x	x
Enterprise-wide		x			x	x

FIGURE 2 Likelihood of KM success

to achieve improvements and predictable, repeatable, consistent outcomes. Efforts to gather what works, and to build upon the improvements of others, represent fruitful means of applying KM to production environments.

Moreover, not everything that works well is a best practice: I recall one instance in manufacturing when a field engineer had circumvented a broken safety lockout to return a line to operation. Seeing the expression on my face, he smiled and said, "that's why they call it field *engineering*." While this entrepreneurial soul was unlikely to submit this approach for consideration, appropriate KM can sometimes gather and proactively eliminate (less obviously) dangerous ideas as well as promote safe and effective practices.

Research and technical teams tend to benefit more from applications that locate and engage expertise—either within or beyond the their organizations—and from tools that enhance collaboration. This, too, is unsurprising. Product or process development is characterized by multifaceted investigation, serial problem-solving, and experimentation of all kinds. Systematically seeking relevant experts—or colleagues who may have had similar experiences—is a promising strategy for accelerating discovery, overcoming roadblocks, or stimulating creativity and innovation.

Maintain Focus

Finally, there is temptation to craft broad-based KM initiatives rather than select just the most effective techniques so solve particular problems. This temptation is entirely understandable: even incremental benefits are still, by definition, beneficial, so extending the scope of an initiative to include more groups would seem to increase the potential return on investment. However, research and experience show that projects with multiple or diffuse objectives are much more likely to fail than those with limited, defined, measurable objectives, and a clear path toward achieving them. This path includes a defined strategy for improving knowledge management, a defined user community, and an approach that is well suited to the objectives, strategy, and community.

APPLYING THESE LESSONS TO PLANT OPERATIONS

If the preceding section provided a general set of recommendations and admonitions about knowledge management, what should we make of these if we consider applying KM to mining and mineral operations? Nothing in the foregoing section is particularly inappropriate; while there is a tendency among our clients to regard their respective industries as unique, in fact each has both distinctive and very common features. Mining, for example, is distinguished by factors such as high capital investment and energy expenditures, but shares with other industries the accelerating pace of change and increasing pressure to contain costs. KM can work in mining precisely as it has worked elsewhere.

With that said, several key lessons are particularly important for plant operators, and thus merit discussion here. These might be summarized in terms of the following statements:

- Begin with objectives, then determine methods.
- Secure management commitment and allocate adequate resources.
- Attend to the details in design and deployment.

This final section of this paper will be devoted to considering each of these, in turn.

Begin with Objectives, then Determine Methods

Mining and mineral operations are in many interesting respects highly diverse. Even at a single facility, the processes and materials used are often strikingly different one from another. The kinds and levels of technical expertise required for success are likewise extremely broad. Even the challenges faced by a single facility might range from energy inefficiencies to ore body composition problems, and from equipment malfunctions or shortages to unpredictable market fluctuations or materials sourcing breakdowns. Many of these challenges would seem to be candidates for KM solutions. Thus, selecting an appropriate target—a problem to be solved or an improvement to be made—is a critical first step to developing an appropriate knowledge management solution.

We have worked with many clients to conduct rigorous information assessments to identify where and how to apply KM. In each case, we begin with users' information needs: what do people need to know to do their job as well as possible? We then study the information and knowledge available to those people, and assess both the gaps and the probable impact of those gaps. Pick the most important work that is suffering the most from poor information usage, and you are very likely to identify the right need for KM. Then it is a matter of articulating that need in terms of some basic questions:

- Who is the user community?
- What functions or processes are we trying to improve, and how?
- What improvements are we trying to bring about?
- What is the probable impact of those improvements?

Answering these questions brings into focus the objectives to be achieved through a potential KM effort.

Once the user community and the improvement that is sought are understood, select a method or KM approach. For instance, should you promote collaboration primarily, or focus on providing external information? We have worked with clients who have inverted this process: one organization became enamored with collaboration software and looked for teams who could use it. We have rarely had a profound success with

these projects. Where we understand what we are trying to do first, and select the KM approach that is mostly likely to be successful and genuinely valuable, however, we are highly to succeed, and to do so relatively quickly. If you identify that engineers consistently need help diagnosing process inefficiencies, and this results in lost time and reduced margins, then developing a system to connect those engineers with the right experts, and/or providing them with documented best practices, will likely result in improved margins very quickly indeed.

Secure Management Commitment and Allocate Adequate Resources

This should go without saying, but in this paper...it won't. Management must vocally and tangibly support an effort for it to succeed. Grassroots KM efforts can work, but they represent a low-percentage bet, especially in environments where resources are sorely stretched. Even if all of your plant engineers believe that an online forum would help them solve problems or better prioritize projects, without sustained management support, the forum is unlikely to be built, and if built, it is unlikely to see sustained productive use. The engineers will simply be too busy to use the forum, until it truly becomes part of how they do their work. Getting to that point requires commitment, creativity, and will. KM must be reinforced and supported at all levels of an organization.

KM projects are resource intensive because they are inherently multifaceted, and because they ultimately rely on changing user behavior to succeed. A director of Research at a pharmaceuticals company once remarked to me, "knowledge sharing is an unnatural act." His somewhat offhand comment is, in some respects, quite true, and sustained change means not only teaching people the act, but making it natural in their environment. That requires more than information technology. It requires sound management support and adequate resources—including time—to bring it about.

One technique for increasing the likelihood of management support is to define the proposed KM project *primarily* in terms of its objectives (provided the right objectives are chosen). Consider this proposition: "We know that we need new ingot forming processes commercialized in 18 months, twice as fast as we have ever commercialized anything of this magnitude. We want to give the team better access to expertise to jump-start their efforts and to help them problem-solve." I contend that it is much more likely to pique the interest of funding managers than an old-fashioned, KM-centric proposition: "Everyone agrees that the organization will benefit from better access to expertise, and so we need to build a system to enable that. We think a good first community is the project team on next-generation ingot forming." That contention has been borne out by experience. Senior management is willing to fund KM measures that are demonstrably likely to help the organization achieve its well-defined goals. The clarity with which this case is made often determines the level of funding and support provided to these initiatives.

The second technique, of course, is to scope the project to fit the actual (or anticipated) level of commitment and resources. Select the right size problem, the right size user community, and the right level of functionality. All of this comes down to sound judgment: the right project will be robust enough to deliver significant, ongoing value, within the constraints imposed by circumstances. KM visionaries within an organization are sometimes hard to limit, seeing potential benefits more clearly than barriers and challenges. Indeed, re-scoping an application from an enterprise-wide, all-encompassing knowledge resource to a focused team space might, at first, seem disappointing to some. That disappointment should be mitigated by the increased likelihood of project success,

and by confidence that the re-scoped project does offer significant value to the organization. Finally, if the application is well-designed for extensibility, then the investment made to solve the first problem can be re-used again and again, creating a common infrastructure for knowledge-sharing across communities and over time.

Attend to the Details in Design and Deployment

The focus of this paper has been on selecting and defining the right projects. This is critically important for success. However, the research also identified several success factors that pertain to how the system is designed, implemented, and deployed. Mary Poppins may have been right: “Well begun is half done.” The other half, however, involves the critical success factors of content organization, interface design, content management, and adequate attention to behavioral change. It is impossible to exaggerate the potential of each of these factors in the success or failure of KM applications.

Content organization. Users must be able to find the resources they need, even those they do not know they need. To achieve this level of usefulness, the system must organize and deliver content in straightforward and intuitive ways. For diverse operations, this often proves difficult: geologists, metallurgists, and mechanical engineers might even use the same terms to denote different things. This challenge underscores the importance of organizing content according to a commonly-understood, easy-to-use framework.

We call these content frameworks “taxonomies,” borrowing the term from classical biology. The biological taxonomy organizes species according to their inter-relationships, clearly and predictably (at least to biologists). Content taxonomies should likewise organize information in ways that are clear and predictable to members of the user community. In our work in this area, Teltech consultants apply the following guidelines to implement clear, highly-useful taxonomies:

- Categories should cluster together like elements (no “apples and oranges” categories).
- The level of detail and breadth of categories should be reasonably consistent.
- Content should be fairly evenly distributed across the taxonomy.
- Categories and subcategories should be mutually exclusive and collectively exhaustive of the content to be categorized.
- Terminology should be consistent and clear to the user community.

Such a structure helps users directly by allowing them to browse to the information they need, finding like resources clustered together. The structure can also be deployed to help search engines improve relevance and completeness of automated searches.*

Interface design. Everyone asks for an intuitive interface, but people’s intuitions vary markedly. There is no single, right way to build user interfaces, but many proven methodologies exist. In our work, we focus on applying sound principles of usability (on which perhaps too much has been written) and iterative development. We test extensively using actual users of the emerging system.

Some production environments pose challenges for traditional interfaces, for instance, if shop floor kiosks or ruggedized equipment do not provide the same user

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* Much has been written on effective taxonomy development for KM applications, some of it by Teltech.

experience as traditional desktop machines. Some applications feature multiple interfaces for different applications; this approach also supports very different uses of a system, contrasting for example, an equipment operator looking for maintenance instructions with a senior engineer seeking an expert to engage in problem-solving. Other applications develop a common interface designed to work for all environments and uses. Either approach can be effective; the important caution here is to take interface design seriously and to assure that the resulting application is maximally useful for its intended purposes.

Content management. Content is the heart of the system. Too often, though, application owners invest more in system maintenance than in content management. Assuring that the system contains the information that users should expect, and maintaining the accuracy, relevance, timeliness, and completeness of that information, is a major challenge that must be successfully met for the solution to succeed over time. If users do not find what they are looking for, or if they find erroneous or too much irrelevant information, they won't come back, and on that basis alone the system will have failed. Content management processes must assure that the system delivers relevant and accurate information consistent with user expectations.

Behavioral change. We have already addressed some aspects of this challenge, but its magnitude and importance makes it a fitting, final topic in this paper. Every situation is somewhat different. At the onset of our work with clients, we begin to identify the key drivers likely to promote more effective information sharing, and the barriers likely to inhibit this change. Very often, the second list is longer than the first. However, if the KM application is truly targeted at the right people with the right problems, the promise of a new resource is itself a significant driver, at least in the short term.

Once the behavioral landscape is understood, the next step is to create a strategy aimed at directing and promoting that change on an ongoing basis. Many major companies are currently engaged in Change Acceleration Process (CAP) initiatives to promote a range of programs; other proven approaches, both branded and unbranded, also exist. Teltech's approach to behavioral change is informed by the work of Edgar Schein and focuses on identifying and using the primary drivers of that change (Schein 1992). Management support and communication naturally factor prominently as primary change drivers, especially the tacit communication that takes place when management rewards behaviors or allocates resources in times of scarcity. People then come to understand what is really important.

As with interface design, there are many ways to successfully change behaviors in an organization. The greatest risk is in underestimating the importance of these efforts with respect to deployment of knowledge management.

CONCLUSION

Throughout this paper I have tried to present the fundamental idea that KM ought to be used as a means to affect other important changes in the organization. Knowledge is a strategic asset that is frequently misunderstood. It can only live up to its power when it is deployed to *do something*; the value of KM is inextricably linked to the importance of the task to which it is applied.

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People and Organization

or

Treating People Like Humans!

Engineered Management Processes

Francis R. McAllister*

SYSTEM ENGINEERING

Years ago, while attending Harvard's Advanced Management Program, Professor Robert Hayes introduced our class to the, then not-so-familiar, concept of systems engineering. First assignment—dinner at The Benihana of Tokyo Restaurant! Delighted, but a bit mystified with the assignment; we had dinner at Benihana.

Back in class, Professor Hayes inquired about the assignment and persuaded us; that Rocky Aoki's business formula for Benihana was not necessarily Japanese cuisine, but rather the systematic way in which he moves more people—if you will, processes more people through his restaurants than his competition, by systematically linking all restaurant functions. For instance, the bar is a holding area in which patrons ideally wait no more, or no less, than 20 minutes. When seated, your table, which accommodates eight, is filled with eight even if you are a party of two. The Japanese chef is also the entertainment, and when, at the end, he cleans the grill, you are being subtly prompted that dinner is over. The bill accompanies ice cream, systematically delivered shortly thereafter. You are expected to pay promptly and depart, as there are eight more, mostly unacquainted, people who have waited 20 minutes in the bar, and who are assembled ready to be seated at your table.

For me—this was electrifying. I understood the concept, concluded it was very powerful and felt prepared to conquer whatever, by means of its application. That was years ago and I can safely say I have yet to fully realize on the euphoria of that moment. Why? Well, I simply conclude:

- The concept of systems engineering is simple and not revolutionary, but
- The application of systems engineering is far from simple and is revolutionary.

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Said differently—The concept of systems engineering is simple, yet, even though we have plenty of how-to advice, we fail to grasp the single-minded discipline required, or are unable to muster the support necessary for implementation of its powerful force.

Nevertheless systems engineering embodied in the ISO process became a quiet management revolution during the decade of the 1990s. And most managers now claim to be advocates and embrace one form or another of systems engineering in management.

Was this anything new or did anything change; for in actuality even the lack of system in management is a system, albeit crude and inefficient? I suggest a factor of change grew from comparisons of management style and a growing awareness of the undefined systems behind those styles. It was in the discovery that systems such as the assembly lines created by Ford could be duplicated and engineered to provide rigor and discipline. It was the realization that systems of management can and should be engineered to be sophisticated and efficient. Thus, the practice of systems engineering emerged to become a discipline in its own right.

MANAGEMENT CRISIS

Few managers have degrees in management. Yet most of us aspire to be a manager. Peter Drucker, famed professor of management, explained the phenomenon of the manager in his 1954 text classic, *The Practice of Management.* Drucker declared—

> *The manager is the dynamic, life-giving element in every business. Without his leadership the "resources of production" remain resources and never become production. In a competitive economy, above all, the quality and performance of the managers determine the success of a business; indeed they determine its survival. For the quality and performance of its managers is the only effective advantage an enterprise in a competitive economy can have.*

Pretty profound; who wouldn't want to aspire to be a manager? Drucker goes on—

> *...The emergence of management as an essential, a distinct and a leading institution, is a pivotal event in social history. Rarely, if ever, has a new basic institution, a new leading group, emerged as fast as has management since the turn of this century. Rarely in human history has a new institution proven indispensable so quickly.*[1]

A footnote; Drucker's 1950s commentary never mentioned systems or engineering.

I dare say, even though Drucker overstates his case a bit, we as managers aren't fully living up to his billing. Edward Deming, a highly regarded western management consultant who practiced widely in Japan, agrees. His 1986 book, *Out of the Crisis*, provides 14 management essentials. Among them Deming suggests management

2. Must "...awaken to the challenge,...learn their responsibilities, and take on leadership for change."
5. Must—"Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs."
7. Must—"Institute leadership." For he says, "The aim of supervision should be to help people and machines and gadgets to do a better job."
13. Management must—"Institute a vigorous program of education and self-improvement."

14. And must —"Put everybody in the company to work to accomplish the transformation."[2]

What is this crisis that Deming asserts? We are managing, are we not? We are now applying the discipline of systems engineering, are we not?

Deming felt the crisis in management to be the forces of unrelenting competition, not just company to company, but more importantly, country to country. Deming's book echoes his concern by describing the phenomenal management successes in the Japanese auto industry. It was a warning to managers in the American auto industry who he felt were falling behind their Japanese counterparts.

He was correct. Today some Japanese automobile manufacturers are dominant in the cost and quality arena for cars.

I drive a Lexus. It's not the least expensive to buy, but I find it the cheapest car I can drive because it is highly dependable, requires little service, is good for 10-plus years and retains its value.

The Toyota management system, from which the Lexus emanates, is highly emulated world over, by well-managed companies. See the November 17, 2003, *Business Week* cover story, Can Anything Stop TOYOTA?

Yet, even the *Business Week* story fails to get at the essence of Toyota's management success. So, what is it that Deming and Toyota are trying to get at?

SYSTEMS THINK

In 1990 Peter Senge wrote what is already becoming a classic management book on systems thinking entitled, *The Fifth Discipline.*

Senge explains:

> *"Systems thinking" is a discipline for seeing wholes—It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots."*
>
> *It is a set of general principles ... spanning fields as diverse as the physical and social sciences, engineering, and management.*
>
> *It is also a set of specific tools and techniques, originating in two threads: 1) in "feedback" concepts of cybernetics and 2) in "servomechanism" engineering theory dating back to the nineteenth century...*
>
> *And "systems thinking" is a sensibility—for the subtle interconnectedness that gives living systems their unique character.*

For clarity, "cybernetics" is the science of communication and control of both human and machine, and "servomechanism" is an engineering term for an automatically operating device for the regulation of a system's variables, actuated by the difference between the actual and a desired value of such variables.

Concluding Senge's thoughts:

> *Today, "systems thinking" is needed more than ever because we are becoming overwhelmed by complexity.... Humankind has the capacity:*

- *To create far more information than anyone can absorb,*
- *To foster far greater interdependency than anyone can manage, and*
- *To accelerate change far faster than anyone's ability to keep pace.*

Certainly the scale of complexity is without precedent…organizations break down, despite individual brilliance and innovative products, because they are unable to pull their diverse functions and talents into a productive whole.[3]

What Deming has in mind, Toyota has in practice. It is simply this ability to see interconnectedness and thus to pull diverse functions and talents into a productive whole.

MANAGEMENT PARALYSIS

This isn't really new. And as said earlier, most managers now claim to be advocates and embrace one form or another of systems engineering in management. Still many fail to truly embrace the revolution. Why is this?

- Is it the "manly" issue?—We know what we're doing; we don't need directions.
- Inertia?—If it ain't broke, don't fix it.
- Incompetence?—I'm doing it the best I know how.
- Cultural?—We don't do things that way.
- Indifference?—We don't have time to take that on.
- Is it the doubter in us?—We've tried that before and it doesn't work.
- Is it a budget problem?—It takes too much time and money.

In our industry, managers of "good" mines sort of get a pass on this question, since the definition of a "good mine" is one that can withstand utter mismanagement. And managers at poor mines spend their time fighting off the buggers over issues that, if not systematically managed, become worse with time. ("Bugger" is a euphemism for all problems, be they customers, suppliers, employees, unions, MSHA or DEQ officials or—the usual suspects—our bosses.) For those who don't fall into the above categories:

- Who have tired from evenings disrupted with calls from operations,
- Who don't like to find themselves constantly on crusades to fix problems,
- Who are finding less and less quality time on or off the job,
- Who want to go home and stay there until they are next scheduled for work, and,
- For those who truly want to be professional, make a difference and leave a legacy;

there *are* effective tools that have been developed to assist the manager.

MANAGEMENT TOOLS—SYSTEM ENGIAEERING PRACTICES AND TECHNIQUES

You know their names and their acronyms:

- Management practices, which advocate systems thinking, include
  - ISO—The chronicling of work practices

  - DNV—The identification and analysis of critical tasks
  - Labor management productivity teams
  - Training
  - Work practice certification and recertification
  - Inspections/audits
  - Performance measures
- Quality engineering management practices, which include
  - Systems engineering
  - Critical task analysis
  - Continuous improvement
  - Best practice
  - Six sigma
- Maintenance practices, which include
  - Assembly line planned maintenance
  - Planned maintenance and component change-outs
  - Predictive maintenance
- Computer assistance tools, which include
  - Control systems
  - Documentation systems
  - Audit systems

There is nothing profound or complete about this list and I don't advocate one over another. I hope you at least recognize some of the tools and I suggest you make the pursuit of one or the other of them in your passion as a manager.

ISO PROCESS

For example, let's examine ISO that stands for International Organization for Standardization. ISO is the world's largest developer of management system standards. An ISO process would typically include the following:

- Define the work process or task to be performed.
- Document the work process or task in a controlled procedure or work instruction.
- Ensure that the work process references, the required procedures, and relevant work instructions.
- Train employees and maintain auditable records.
- Ensure that the procedures and work instructions are available to employees at their work area or specific work station so as not to disrupt the task or process.
- Perform the required internal audits:
  - Help provide root-cause analysis of non-conformances.
  - Close-out non-conformances with effective corrective action.
  - Supply the required records for the next audit.

While no reference is made to critical task analysis, best practice or continuous improvement (Kaizen in Toyota-speak), these too are elements of the process. Six-sigma can be considered a rigorous further refinement or separate approach that embraces the engineering-out of process flaws.

For managers today, these are state of the art in management practice. What does it take to have us embrace these techniques?

MANAGEMENT CHANGE BY CRISIS

Many have pursued these practices as a matter of business improvement. Unfortunately many will also look back to a particular crisis that dictated a change in management approach. Let me share with you three such instances.

Amarillo Refinery—Early 1990s

The quality of Asarco's Amarillo Refinery copper rod had fallen behind that of our competitors, making it particularly difficult to sell. The company had a huge investment in the rod plant and it was a major element in our marketing plan. Some suggested newer rod-rolling technology had bypassed our technology and we would ultimately have to exit the rod business. The plant manager determined to end the crisis. Having heard about ISO, the plant began implementation of the process as a means of certificating the quality of our rod.

The plant's day shift, the "A Team," produced good quantities of quality rod. The swing shift did not meet the same standard. And the night shift was worse. Management had previously attributed this to our most experienced operators bumping to the day shift, thereby putting them on the A Team. In implementing ISO:

- The plant employed specialists to document the process—this failed.
- The plant turned to the supervisors to document the process—this too failed.
- The plant turned to the operators to document the process—this succeeded.

The postmortem suggested that specialists and supervisors simply could not come to understand the operators' procedures sufficiently to produce adequate documentation. This learning was very helphil in subsequent ISO implementations.

The result was nothing short of sensational:

- Production went up by 25% and our quality became the industry standard for very simple reasons:
  - The procedures used by the A Team were now standard for all shifts,
  - Procedures used by the A Team that had contributed to poor quality and production of the other two shifts were identified and eliminated, and
  - Communications between shifts and between workers on the same shift were radically improved because each operator now understood the impact that properly performed duties had on the whole system.
- Amarillo concluded the results were so outstanding they implemented ISO plant wide. They then were the standard for what became known as the Asarco Management System or AMS an ISO based management derivative we developed.

Ray Mine—Mid-1990s

Production disrupted by heavy rains, the mine struggled for months not just for ore but also to keep equipment maintained to meet the heavier demands placed for stripping requirements. In the mine one morning, five of the 14 trucks scheduled to be operating were idle in the mine filled with ore. Inquiring of the fleet status, the response was not to worry, each of the five had a maintenance problem and a service truck was currently "scrambling" to get them running.

Not in the least satisfied with the scrambling response and the feeling that this was a crisis, I discreetly inquired of an outside maintenance company we used extensively, of their opinion of our maintenance practices. "Worst in the industry" was their measured response confirming the crisis.

That same week I attended an operating committee meeting at Montana Resources (MRI). Following a particularly good report on maintenance, I inquired about maintenance practices and learned that a few years back MAO (now Ruston) had installed a systematic maintenance system for MRI. It had required the addition of a maintenance planner and had materially reduced maintenance expense and increased availability.

With that information, I returned to Arizona where we asked Ruston to perform an appraisal of our maintenance practices and recommend a plan of action for the Ray Mine. What resulted was the addition of maintenance planners, which facilitated adoption of a systematic Assembly Line Planned Maintenance process and Scheduled Component Change-Outs.

The result, after the fleet was back into shape, was a materially lower maintenance cost, increased availability and vastly reduced numbers of in-mine breakdowns. These maintenance practices were then implemented at all of our mines and at our smelters and refineries with equal results.

In 1999, when engaged in merger discussions with CyprusAmax, an outside due diligence audit of our maintenance practices put Asarco in the top quartile of maintenance performance.

Stillwater Mine—Mid-year 2001

The mine was being developed to increase production from 2,000 to 3,000 tons per day. In rapid succession we had three fatalities in the mine. There is no way to describe the emotions we all felt. This was unacceptable. It was a major gut check and it was a crisis in management that had to be ended then and there.

We had mine safety stand-downs. We instituted joint management and labor safety inspections. We created safety committees. We began the long process of installing DNV management control systems, best summarized with the acronym ISMEC and viewed as a primary pathway to safety management success. Frank Bird defines the elements of ISMEC in his book, *Practical Loss Control Leadership.* They include

- ***I**dentification of work.* Specifying the program elements and activities to achieve the desired results.
- ***S**tandards.* Establishing performance standards (criteria by which methods and results will be evaluated).
- ***M**easurement.* Measuring performance; recording and reporting work in progress and completed.

- *Evaluation*. Evaluating performance as measured and compared with established standards; appraising work and results.
- *Correction*. Regulating and improving methods and results by constructively correcting substandard performance and commending desired performance.[4]

Along with ISMEC, Stillwater shifted away from the relatively narrow terms of "unsafe acts" and "unsafe conditions" to the broader "substandard practices" and "substandard conditions." There are three distinct advantages:

1. It relates practices and conditions to ISMEC measurable standards,
2. It broadens the scope from accident control to loss control thereby encompassing not only safety, but production, quality and costs, and
3. It avoids fixing blame.

A key component of the DNV–SMEC pathway is task analysis. Task analysis is the systematic examination of a task to identify all loss exposures associated with the task. The objective of the process is to help supervisors, executives and hourly employees apply a systematic, practical approach to preparing and using task procedures and work practices. As in the Amarillo Refinery example, the operators, who are the task experts, are utilized to analyze task steps, pinpoint loss exposures, make efficiency checks and develop procedural steps that control loss and improve process efficiency.

Task analysis at the Stillwater Mine is a work in progress. To date, 35 job categories have been identified. Within those job categories, 1,355 tasks were identified and analyzed. Resulting from the analysis, 269 tasks were determined to be critical and have had procedures drafted. Drafted procedures are being reviewed, approved and implemented.

We are currently implementing a task observation system that utilizes the recently completed task procedures. Task observations ensure procedures are adequate as changes occur in the workplace or employees identify better ways of doing things. Another benefit of the observations is they give management the assurance that every employee is properly trained and has demonstrated competency in performing the critical tasks required of their job.

CONCLUSION

The mining industry has gone a long way towards adopting good management practices. However we should not be waiting for a crisis to motivate us to action to do more. There are plenty of other motivating reasons a few of them being:

- Health and safety, the first
- Professionalism, or just doing the right thing
- Development of managers and employees
- Quality of our professional and personal lives
- Portability of these management skills
- The legacy of our stewardship

Let me repeat the billing given managers by Drucker—

> *The manager is the dynamic, life-giving element in every business....the quality and performance of its managers is the only effective advantage an enterprise in a competitive economy can have.*

The challenge given managers by Deming—

> *Managers must…awaken to the challenge,…learn their responsibilities, and take on leadership for change.*

And the solution given managers by Senge—

> *"Systems thinking" is a sensibility for the subtle interconnectedness that gives living systems their unique character.*

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Managing with Workforce Culture in Transition

Gregory E. Mahoski* and Ronald D. Mariani*

BACKGROUND

The steel and iron ore industry has had a long history of an adversarial relationship with its union and workforce. The Empire Mine during its first 40 years of existence was no exception. The "we-they" mentality went hand-in-hand with the normal by-product of an adversarial relationship, grievances and arbitration.

This relationship was considered the norm and it was not until the late 1970s that consideration was given to changing this relationship. At this time the industry was involved in a fight for existence and the economic pressure demanded increasing productivity to lower cost. The challenge to survive highlighted the fact that an adversarial relationship was not conducive to attaining the needed gains in productivity.

The first formal attempt to change the way we worked came in the 1980 Labor Agreement which provided for the opportunity to utilize Labor Management Participation Teams (LMPTs). LMPTs were established at the Empire Mine and they functioned for a couple of years. The teams spent most of their time working on creature-comfort issues and steered clear of dealing with productivity issues. Mine shutdowns had occurred in Michigan resulting in large layoffs, and the union was trying to add jobs and was not supporting teams that could increase productivity and eliminate jobs. When the 1986 labor negotiations began, the local union pulled their support of the LMPT process.

Other initiatives were negotiated over the years to foster a change in the culture but, as with the LMPT program, they did not produce the desired culture change. It became abundantly clear: you cannot negotiate a culture change.

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WHAT STARTED THE CULTURE CHANGE

An operation economically challenged to survive, a newly elected union leadership team committed to making the mine survive and a management team adopted a different management style. These ingredients coupled with a shared need—survival—have been the catalyst for the change in culture we are experiencing. The changing culture is the direct result of employee involvement.

MANAGING WITH THE CULTURE IN TRANSITION

Using the following as guidance has helped to support and expand employee involvement which in turn is changing the culture:

- The objective of involving employees has been to safely improve productivity and lower cost. We are working collectively to secure our future.
- Jointly implementing a behavior-based safety program
- As much time and energy as was spent in the adversarial mode is required to support the changing culture, however, discussions are now proactive instead of reactive. The key principle that is followed is treating people the way you expect to be treated.
- Communication can never be overdone; as the workforce becomes involved in the business there is an ever increasing need to share information.
- As employees' roles change there is a need to increase training activity.
- Employee involvement is not co-managing; it is still management's job to manage.
- When there is disagreement, do not give in to the temptation of managing the "old" way.
- Empower the workforce and maintain accountability.
- Utilize a team problem-solving process.
- Don't provide the answers; provide the information that will allow employees to develop the answer. This maximizes employee buy in.

CONCLUSION

The time and energy that has been expended in support of this process has been very gratifying and it is bringing positive results to the bottom line. Employees are proud of the achievements they have made while following a plan that they had input on. We are convinced that this is a process of continuous improvement.

Some managers were apprehensive about this process as they felt they were going to relinquish authority. In actuality, managers who have encouraged and supported involvement of their employees find their status enhanced. Employees will go the extra mile for a leader who treats them fairly and seeks their input on operational issues.

Linking HR Systems for Better Performance and Employee Involvement at Kennecott Utah Copper

Chris Crowl*

Employee involvement does not directly correlate to performance improvement. A key ingredient is the introduction of new Human Resource Systems that promote both performance improvement and employee involvement. Many organizations have tried to use employee involvement as the "fixer" of performance issues—and seen their performance deteriorate further. They failed to realize that the entire human resource strategy must be connected to the goals of performance improvement and that greater employee involvement is only one tool in that strategy.

So what are Human Resource Systems? These are systems that all managers use to get work done. Most of us are familiar with basics such as planning, assigning work, checking progress (auditing), completing assignments. We also commonly think in terms of staffing, training, compensation, or corrective action. All of these are human resource systems. All must be designed to support what you are trying to accomplish with your people. We call that the Human Resource Strategy. Let's examine one part of a total strategy intended to support more employee involvement at Kennecott Utah Copper—the hourly job structure.

The design of hourly jobs directly affects how many employees of different capabilities are required to get the work done. It begins to answer some fundamental questions:

- What are the roles and accountabilities of each employee?
- Do they have enough information to make decisions, to take responsibility for their work?

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* Kennecott Utah Copper Corp., Bingham Canyon, Utah

- What kind of capabilities do they need and is the company prepared to train for these skills?
- Will we hold them accountable for using the skills in their jobs?

These are not Human Resource Department–driven decisions—they belong to all of management. All of management is responsible for the culture they want to create and for driving to higher performance outcomes.

COLLAPSING THE NUMBER OF HOURLY JOB TITLES

In early July 2002, Kennecott Utah Copper made a decision that we needed more engagement by our hourly employees. We needed them to be aligned to our efforts to improve productivity and reduce costs. We also believed that we needed a more flexible workforce, with employees able to perform needed tasks as work priorities changed. Finally, we needed to create a culture of learning new skills and using those skills to improve business performance.

We established a team of managers and supervisors to redesign our hourly job system. Before the redesign, we had 176 job titles over nine pay grades. The new system would have fewer pay levels for advancement, would be based on having acquired certain skills before advancement, and finally, would redefine qualifications to include more than just technical skills. Five weeks later, the system had been designed and fully implemented with 1,200 hourly employees having new job titles. After this redesign, we had eight basic job titles over four pay grades. A serious commitment to training allows each employee to demonstrate his ability to stay at his job level, or advance to the next level.

FOUR KEY SKILL AREAS FOR EACH JOB

Four key skill areas are outlined in each job: technical safety, business knowledge, and performance effectiveness (interpersonal and team skills). All employees must have competency in all four skills established at the lowest job level. To be eligible for promotion, employees must demonstrate those higher skills established at the next higher level. Jobs start as Operator C or Craftsman C. Then, advancement occurs to B, A, and the highest level, Advanced Operator or Advance Craftsman, when the company determines that a vacancy exists. Testing is used for each learning module within each job title. Some examples are

Technical:	Equipment operator skills, maintenance skills
Safety:	Establishment of a personal safety plan Accident, property damage, near-miss reporting Conducting safety audits
Business Knowledge:	Basic mine economics (learning map) Goal setting and understanding key performance indicators Computer skills Sustainable Development concepts

Performance Effectiveness:	Team leader and team member responsibilities Task assignments Adult-to-adult communications

Employees earn advancement opportunities based on becoming “qualified” before the higher-level vacancy occurs. We promote the most qualified individual (with seniority being used to break ties). The concepts of seniority have been converted to concepts of “meritocracy” (a system based on merit). People get ahead by being better, performing better, and contributing to operational improvement.

THE JOURNEY CONTINUES

The changes in daily behaviors of all of our employees are significant. Supervisors have shifted their thinking about the development of their employees. Employees have stepped forward to the challenge of learning new skills and applying those skills on the job. They are hungry for more training, more involvement, and they are taking an active interest in improving the business. While many other Human Resource System changes have been introduced, they all contribute to engaging our employees in business improvement. That is our challenge in employee involvement.

Management of Process Technology Development

or

What Fun Does the Future Hold?

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Has Minerals Industrial Technology Peaked?

Robin J. Batterham*

We still need to innovate, but it is getting harder. The real price of metals is declining, return on shareholder value is lower than other industries, and there is a shorter-term focus on staying viable in a capital-intensive industry where timeframes for implementation of new technologies can be long (+15 years).

In this environment, the levels of R&D spent by major minerals companies are remaining steady at around 0.2%–0.5% of revenue. This is not large and to remain viable in the future, we need to be smarter about the way in which we do R&D.

The mining industry is a knowledge-based industry. Driving down the cost curve demands innovation, which demands knowledge. To be smarter and more effective in our approach to innovation, a new paradigm is required. Generating, capturing and using knowledge has evolved from Mode 1 (discipline based and clear distinction between basic and applied research) to Mode 2 (multidisciplinary, team-based approached with flow between basic and applied activities). Mode 2 is now seen to be much more efficient and to deliver better appropriability (Tegart 2003).

To survive, we need to innovate, and the best way to do this is collaboratively. Some examples and pointers for the future will be given in this paper.

THE CURRENT SITUATION

The Rand report and other recent studies have painted a grim outlook for the mining industry. The real price of metals continues to decline (Figure 1) and profit margins remain thin. This is reflected in shareholder returns—which are well below other industries (Figure 2)—and current management strategies—which reflect something of a "survival mode." The current focus for most mining companies is on short-term, incremental gains

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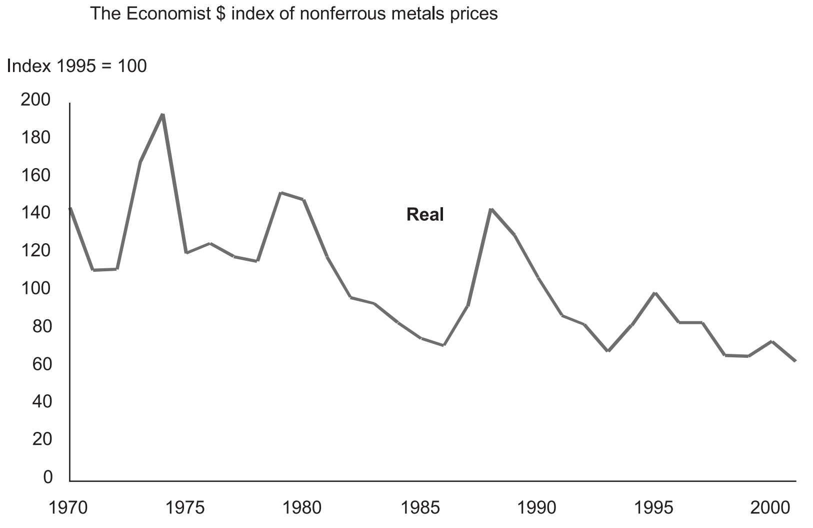

FIGURE 1 Real prices continue to fall

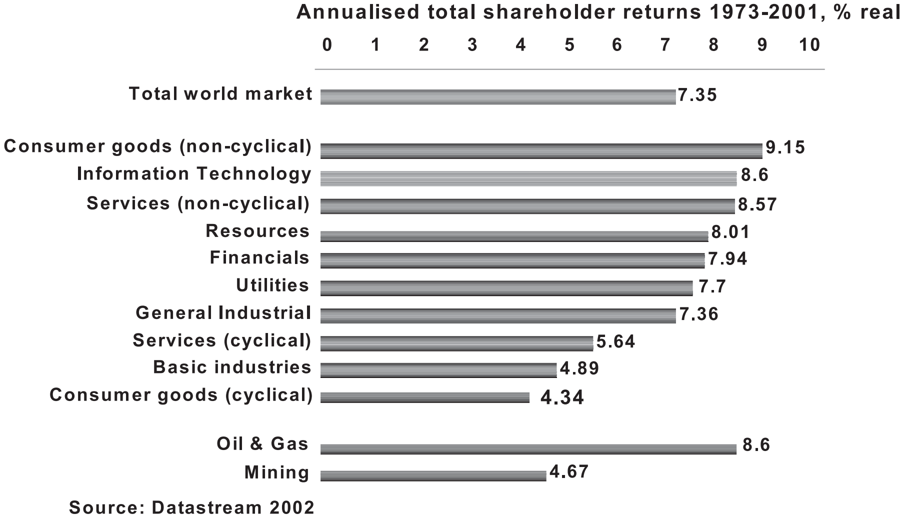

FIGURE 2 Mining returns have been poor

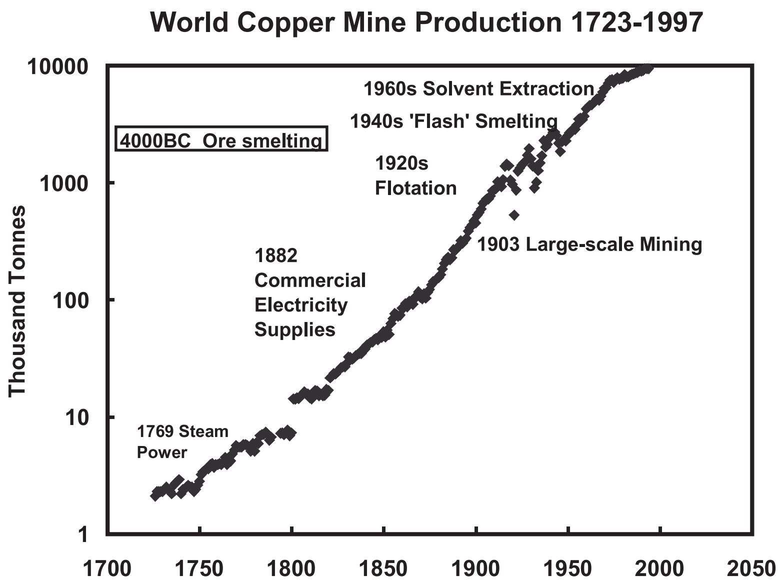

FIGURE 3 Major innovations in copper production

and extension to the life of existing ore bodies. There is an aversion to risk and severe cutbacks on R&D have been experienced.

In this climate, it is not surprising that we would be debating what the implications are for technology and innovation within our industry; and, indeed, speculating as to whether we have seen the peak of technical innovation. This concern needs to be considered in an historical context, but also with the realisation that the pace of change is increasing (some would say exponentially) and the previous routes to innovation may no longer be appropriate.

Innovation Takes Time

The cycle times between knowledge generation (which comes at a cost) and implementation of the innovation (the return on that cost) are often much longer than the typical 1–2-year lag between capital expenditure and cash flows. In our industry, capital is a large component of our costs and so, once having invested, it is difficult to justify changes within a period of 5–30 years. Generally, the more fundamental the change, the longer is the time for implementation since any change must coincide with the capital cycle.

When we look at the list of historical developments in copper processing (Figure 3), there is a tendency to think that there are no more major developments to be had. Where, for example, is the recent equivalent for the development of flotation technology, or copper heap leaching coupled with solvent extraction and electrowinning, or ore sorting? This SME meeting is in fact a timely reminder that similar developments are still occurring but we can expect them to take time to filter through the industry. The introduction of SXEW to copper

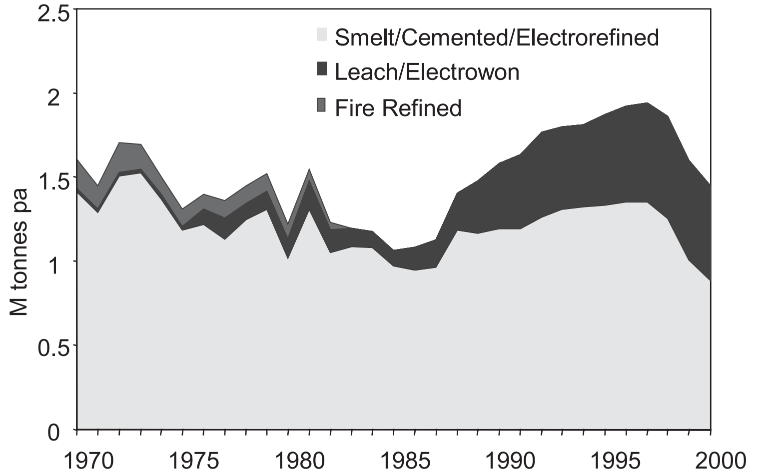

FIGURE 4 US primary copper production by technology

illustrates the point that, even within one sector of industry, it takes at least 20 years for developments to filter through (Figure 4).

However, the current climate would suggest that such long timeframes may no longer be acceptable. The march to sustainability is driving the need to innovate at a far greater pace in order to stay viable.

Innovation Is Necessary for Survival

The march to sustainability will involve mining with a minimal footprint. Ideally, removing only the valuable mineral with limited visual disturbance to the landscape via techniques such as in-situ leaching. However, there are significant technical challenges in interrogation of rock mass, understanding of geomechanics and development of cheaper barriers if we are to see a sharp move in mineral processing towards sustainable in-situ leaching. This all suggests that a considerable amount of R&D is required to underpin the innovation that can realise this dream. Current industry conditions do not suggest great capacity for R&D. The four major mining companies, making up 50% of market capitalisation for the industry, all spend less than 1% of revenue on R&D (Figure 5). This level of spending on R&D in mining, mineral processing and metal production is relatively low, when compared to other industries. Closest on the list are the automotive and chemicals industries at 3%–5% of revenue spent on R&D (Research-Technology Management, September–October 2003).

Brave new frontiers such as in-situ interrogation of rock mass, automation of mining, moving mineral processing to target in-situ leaching, barrier technology and the like require considerable R&D effort. With current economic pressures and consolidation within the industry, the innovation necessary for survival is not just about R&D spending but also the way in which we approach those R&D targets.

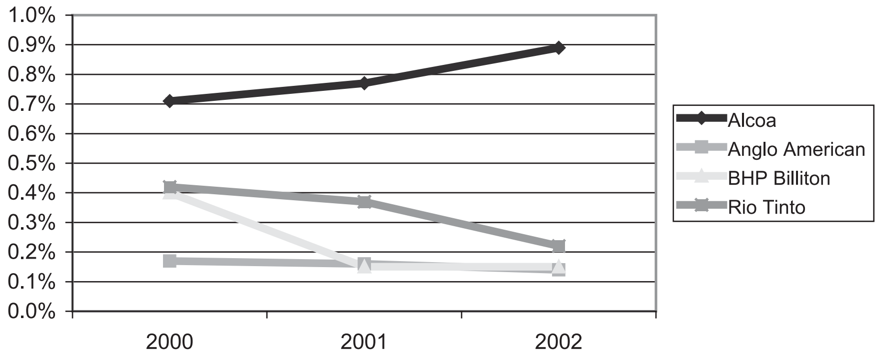

FIGURE 5 **Trend in R&D spending of major mining companies**

A New Paradigm Is Required

The mining industry is a knowledge-based industry and sustainability improvements demand increasing knowledge intensity. To be smarter and more effective in our approach to innovation, a new paradigm is required. It is not sufficient to simply increase R&D spending—in reality, there are limited funds to go around. R&D spending is only one component of the innovation process that sees new technology successfully taken up by the industry.

Generating, capturing and using knowledge has evolved from the discipline-based "Mode 1" to a more flexible, multidisciplinary "Mode 2" approach.

In the past, the Mode 1 method of R&D delivery had been the standard (Figure 6). Activity was discipline based with research groups often operating in isolation. In the core sciences of physics, biology and chemistry, researchers worked on their own projects and even within disciplines a line was drawn between basic and applied research. There was a clear distinction between the theoretical core of any R&D activity and its conversion to applications.

The emerging Mode 2 method of R&D delivery is a different beast (Figure 7). This method is multidisciplinary and team based, with a constant flow of ideas and information between basic and applied research activities. The discovery occurs where knowledge is developed and put to use.

Mode 2 is now seen to be much more efficient and to deliver better appropriability (Tegart 2003). Consider the field on Bioinfomatics and the mapping of the human genome. Biology, mathematics, electrical engineering and IT have all come together to produce, in a very short space of time, the framework and technologies that have significantly advanced the field of genetics. The spin-offs for the health sciences industry have been incredible. The spin-offs for our own industry—in areas such as bioleaching and site remediation—are there for the taking.

If this all sounds a little too blue-sky, then consider other examples with more immediate applicability:

- A better understanding of the basic physics of foams and research into froth stability for the brewing and detergent industries is leading to better understanding of the froth phase in mineral flotation cells. The potential to shift the grade-recovery curve with no loss of throughput exists.

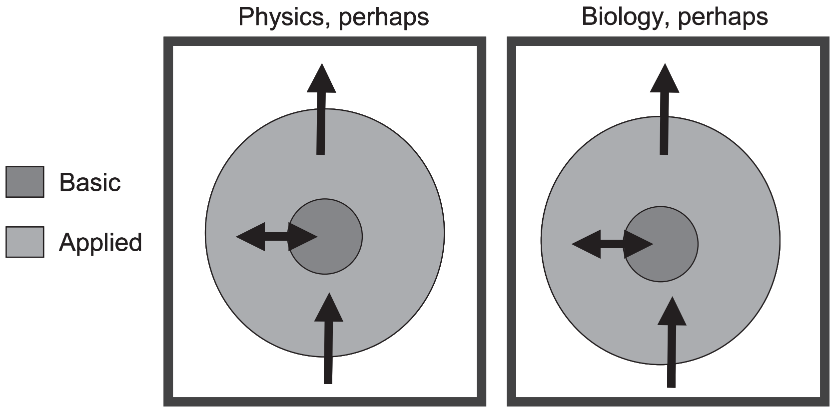

FIGURE 6 Mode 1 method of R&D delivery

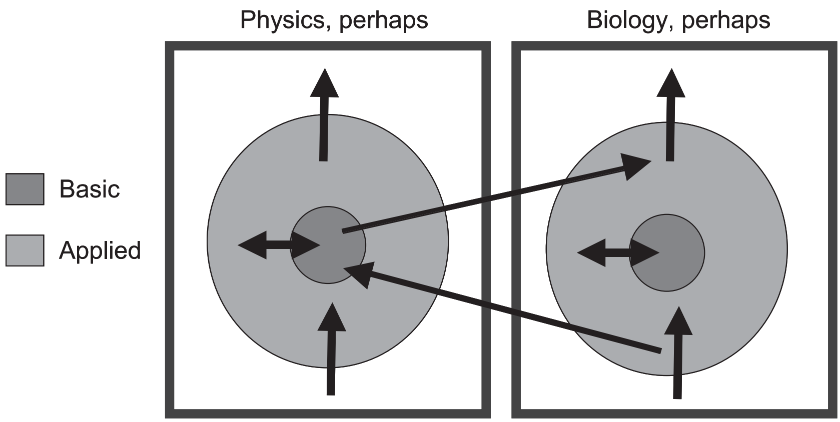

FIGURE 7 Mode 2 method of R&D delivery

- Comminution technologies coming out of the cement industry offer potential for better control of particle size distribution and more energy efficient grinding.
- One company is adapting technology originally developed for the space industry to achieve improved separation efficiencies in mineral sands beneficiation.

These are but a few examples. The key element in all this activity is the multidisciplinary, collaborative approach. The global nature of our industry gives great scope for collaboration, but we also need to think outside the box—looking to other industries and outside our main research infrastructure to achieve the technical innovation necessary for the future.

THE FUTURE FOR MINERALS INDUSTRIAL TECHNOLOGY

There is great scope for further technical innovation. Indeed, it is necessary for the sustainability of the industry. To survive, we need to innovate, and the best way to do this is collaboratively. Alliances between R&D suppliers are needed and broad support from the companies is required. Those alliances will need to extend beyond the current minerals industry research infrastructure to embrace the greater external environment. The global nature of our industry provides a framework on which to build the multidisciplinary, team-based approach to R&D that is necessary for successful innovation.

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Managing Technology Development in a Changing Business Environment

R.D. La Nauze* **and R.C. Shodde***

Major societal and industry changes over the last four decades have influenced the management of technology in the minerals industry. From the authors' experiences in both private and public sector R&D, the paper analyzes the range of strategic and structural changes and provides examples of some key technology delivery responses.

For those charged with managing technology, the two key challenges facing them over the next decade are (1) moving technology development from a cost focus to a value focus (that is, from "how much long-term research can we afford?" to "identifying and capturing the value created from R&D") and (2) the recruitment and retention of key talent.

THE NEED TO ADAPT

"Change is slow and gradual. It requires hard work, a bit of luck, a fair amount of self-sacrifice, and a lot of patience (Greene 1998)." Since the 1960s the world has changed and the minerals industry has had to adapt to the changing circumstances. In the '60s, minerals were there to be discovered and fortunes to be made; in Australia, the World War II embargo on exporting iron ore was lifted and the Western Australian iron-ore boom commenced, to be followed by the exploitation of the Darling Range bauxites; copper, lead, zinc and nickel were discovered and mines developed. The Australian dollar was worth US$1.11 whereas today it is around US$0.65.

The oil crisis of 1976 sharpened focus on the sensitivity of the minerals industry on energy costs. By the late 1970s The Club of Rome was predicting the imminent demise of certain key metals—a prediction that has not been fulfilled—though the signs of the shift

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were there. The minerals industry was losing its shine. More recently "triple," then "triple plus one," bottom-line accountability—a desirable goal—has required the industry to further modify its approach.

These changes have been accompanied by significant shifts in the management of technology. To standstill is to go backwards. This paper reflects on the changes in the minerals industry, on the different responses adopted for managing technology and postulates the next major issues for technology managers.

SO WHAT'S CHANGED?

Industry Structure

During the 1960s, Mt. Isa Mines Ltd. was, for a brief period, Australia's largest company. Last year, it was taken over by Xstrata for a mere A$4.93 billion (about US$3b). During the equivalent period, General Electric's market capitalization went from US$6.3 billion to US$330 billion, to become more than the combined market capitalization of the top 150 minerals companies.

The decline in relative importance of the mining and primary metal production sector to western economies has resulted in relentless change in the structure of our industry. Classical bifurcation of the market into a handful of large companies and a long tail of smaller companies has changed the nature and capabilities for technological delivery. We have witnessed the dual listing of CRA and Rio Tinto, the merging of BHP with Billiton and no doubt further rationalisation to come. The emergence of the traders, Glencore and Xstrata, will initiate a new interesting dynamic. Outokumpu is moving away from mining towards downstream, higher value-added parts of the metal production chain… and so on.

Based on surveys by the Raw Materials Group (1990, 2002) in Stockholm, of the top 50 mining companies in the western world that existed in 1990, only 33 of these survived to see the new millennium, with the other 17 being taken over or broken up. The authors estimate (September 2003) that a further 5 of the original 50 companies have since been acquired and 5 of the original companies have significantly slipped in their rankings—meaning that presently only 23 of the original 50 companies in 1990 are still in the top 50 list today. Of these 23 companies, 9 are state-owned enterprises.

Whilst metals have an assured place in the future, the high attrition rate clearly shows that within the present industry structure, companies are struggling to survive. As a result, the focus is on short-term profit objectives that adversely impact on how companies treat long-term high-risk investments in R&D and exploration.

Declining Value and the Economic Cycle

Over the last 200 years, commodity prices have fallen in real terms on average by 0.6% pa, Figure 1 (JB Were 2001). Superimposed on this downward trend are shorter cyclical movements—the boom/bust of the industry.

One is forced to wonder whether this can be maintained in the longer term. An evaluation (MICA-CRU 2003) of the financial performance of 262 major nonferrous and precious metal mining companies over the last two decades, Figure 2 shows that the industry only generated surplus cash in 7 out of the last 20 years, and that over the period 1980 to 2000 the industry had a cumulative cash deficit of US$38 billion.

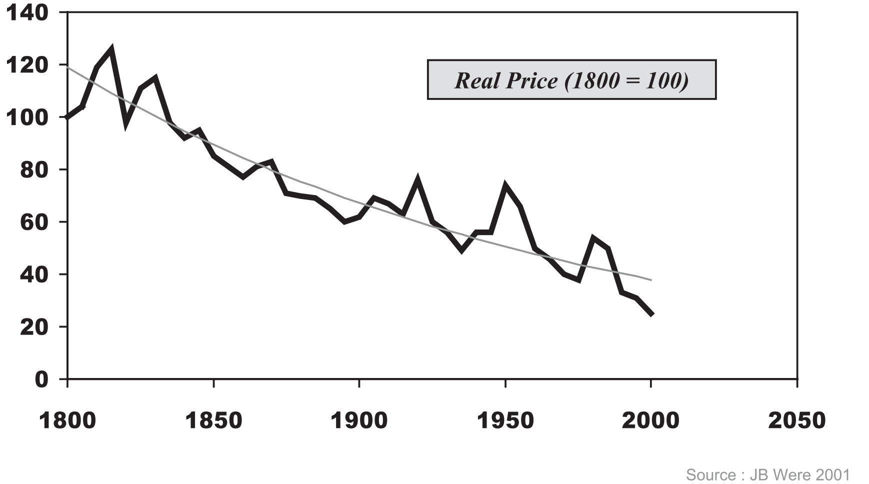


FIGURE 1 Long-term trends in real metal prices, 1800–2000

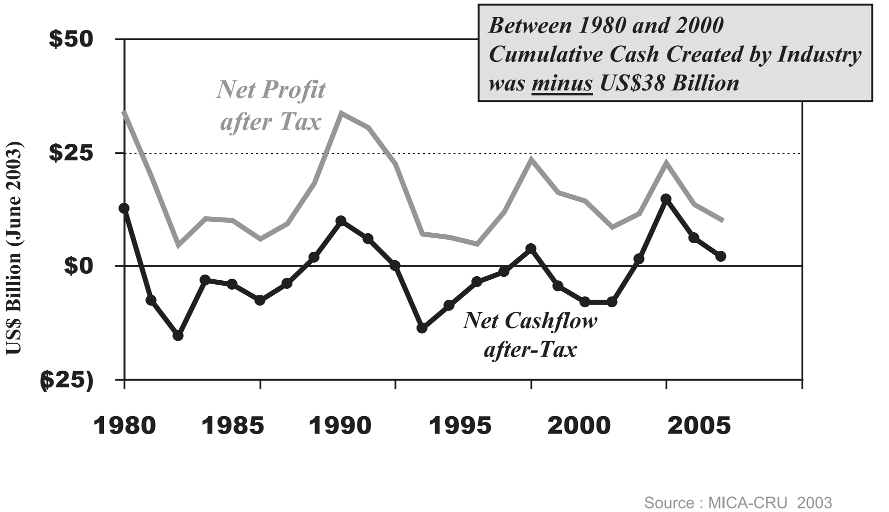


FIGURE 2 Trends in profits and cashflows for western world nonferrous and precious metals mining industry, 1980–2002

The fundamental problem is that the industry is capital-intensive and has long lead times to find mines and build new capacity. It is also reluctant to shut down marginal operations. The lack of supply-side flexibility, coupled with rapid changes in demand, leads to large swings in commodity prices. The industry has tended to overbuild, resulting in extended periods of mediocre prices and low profitability. The challenge for technologists is to develop ways of lowering costs (both capital and operating) and improving the industry's flexibility to break out of the traditional boom-bust cycle.

Societal Expectations

Not only has the economic landscape changed but society's expectations with respect to the exploitation of the earth's riches has also changed. Despite the boom-bust cycle of the minerals industry, which might otherwise hinder the development of technologies leading to environmental significant performance improvements, the industry has not been tardy in responding with responsible practices and auditable reporting of environmental performance (La Nauze and Temos 2002). As the industry has been generally a price taker not a price maker, it has passed on the benefits of lower costs as lower prices to any customer. Whether this was caused by market indiscipline or not, it has meant that consumers do not impugn the full "environmental" cost in their purchase and the potential for improvements beyond those which give high internal rates of returns through cost savings or increased revenue have been difficult to justify.

THE CHALLENGES TO MANAGING TECHNOLOGY

The Chief Technology Officer (CTO) must operate within this challenging and changing milieux. This section outlines some of the challenges and the responses being exhibited throughout the industry.

CTO's Biggest Challenges

The annual survey of Industrial Research Institute members asks Chief Technology Officers what are the "biggest problems" facing technology leaders. The IRI membership is representative of a wide cross-section of US industry although it has only small representation from miners and primary metal producers. Despite tightened economic circumstances, the 2003 IRI survey had "growing the business through innovation" as the CTO's top priority. At the same time, the data also suggests that IRI membership have aligned their technology planning with their business strategy.

For the IRI membership, growing the business through innovation is consistently a long way ahead of balancing long-term/short-term R&D objectives which some would say was the mineral industry's current concern. In the mining industry, where the absolute industry sector size is stagnant and products are not significantly differentiated, the CTO does not have such a clear mandate.

Such a mandate would be clear if there was a demonstrable link between profitability and spending on R&D. Unfortunately definitive proof of this relationship is elusive. Recent data, Figure 3, (MICA-CRU 2001) of the average combined level of expenditures on exploration and R&D as a proportion of sales revenue of 88 large mining companies showed no correlation with return on shareholders' funds.

Recent studies (Schodde 2003) on the exploration expenditure and discovery rates of the mining industry indicate that that the industry has performed poorly in recent

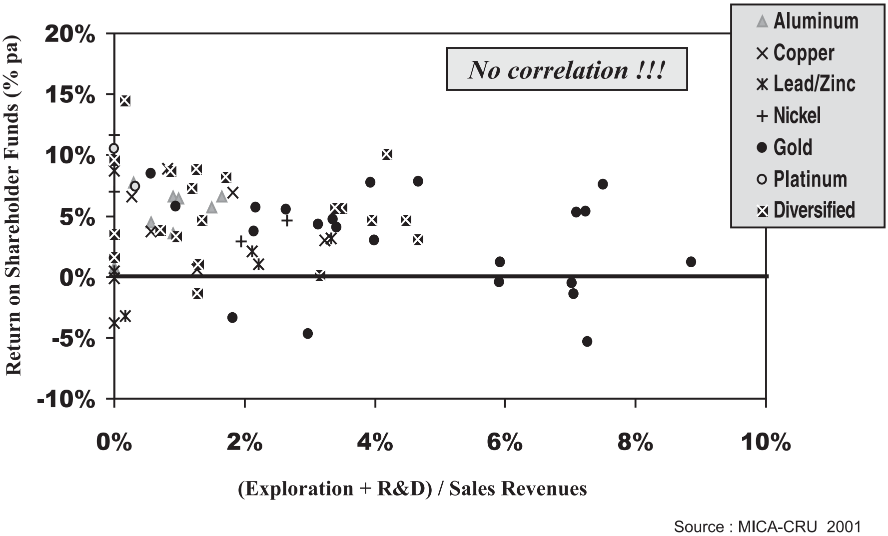


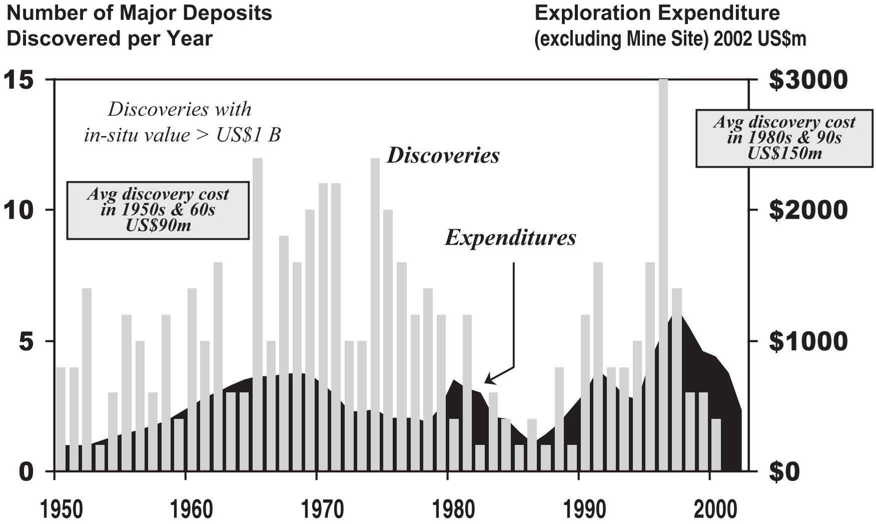
FIGURE 3 Relationship between the level of expenditure on exploration and R&D versus return on shareholders funds for various sectors of the western world mining industry, 1995–2000

years, Figure 4. While the rate of discovery of major deposits (with an in-situ value greater than US$1 billion) has remained fairly constant over the last 30 years, the amount of spent (in constant 2002 dollars) on finding them has risen significantly. In the 1950s and 1960s the average cost per major gold or base metals discovery was US$90 million. By the 1990s this had risen to around US$150 million for a major base metals discovery and US$290 million for a major gold discovery.

The factors behind the decline in exploration performance are complex. Even so, there is a widespread view that "all the easy, out-cropping deposits have been found" and that the next generation of discoveries will require searching for them under deep cover. This is expensive and difficult. It is argued that it is the mediocre discovery performance of the industry that has led to the recent decline in western world exploration expenditures of 72% in real terms between 1997 and 2002 (MEG 2002). The best way to turn this situation around is to be much smarter at how and where we explore. Technology has a key role to play in making this happen.

This phenomenon is not restricted to the minerals industry. Fewer new drugs are reaching the market each year. This is in spite of a 12-fold increase in spending (in real terms) on R&D by the US Pharmaceutical Companies. According to the head of the biotechnology consulting arm of Ernst & Young (Crocker 2003), the problem with the pharmaceutical industry is that "it is simply more difficult to produce new drugs. All the low hanging fruit has been picked and a treatment found for many of the simple illnesses." These concerns echo the same challenges faced by the mining industry.

We speculate that the minerals industry CTO's biggest problem is convincing, and continuing to convince, the CEO that investment in technology stacks up well against other demands on company resources. Unfortunately, major new discoveries and projects are scarce and take time to come to fruition and the industry is facing increased



Source : WMC 2003

FIGURE 4 Expenditure and discovery history for major base metal deposits found in the western world, 1950–2000

mineralogical complexity requiring technical advancements for their discovery and exploitation.

Notwithstanding this, new exploration concepts and technologies can re-invigorate a mature exploration district, such as Chile (Suchomel and Parry 2002). For instance, the development in the 1980s of the solvent extraction electrowinning (SX/EW) process for copper oxide ore, Figure 5, made it possible for the industry to economically mine a new class of copper ore bodies. More recently, major advances in block caving has seen a 70% reduction in the capital cost/tonne mined, further pushing the boundary of exploitable copper ores.

Witherly (1994) suggested that there is an early mover advantage for those companies who adopted various new types of airborne electromagnetic systems. He speculated that introduction of a new system typically leads to significant discoveries within a few years. However, such related technologies are often competing for the same family of targets and consequently the individual technologies quickly become obsolete as better systems are developed. It will be interesting to see how many discoveries can be attributed to the recently launched Falcon airborne gravity gradiometer and whether it can adapt to compete with the next generation of airborne systems already emerging into the marketplace. Experience indicates that the mining industry is very quick to pick up on such innovations. Indeed a strategy of not being a developer but rather a rapid and innovative user is often adopted.

Dry et al. (2002) have analyzed why so few iron direct smelting technologies have become commercially viable. They conclude that

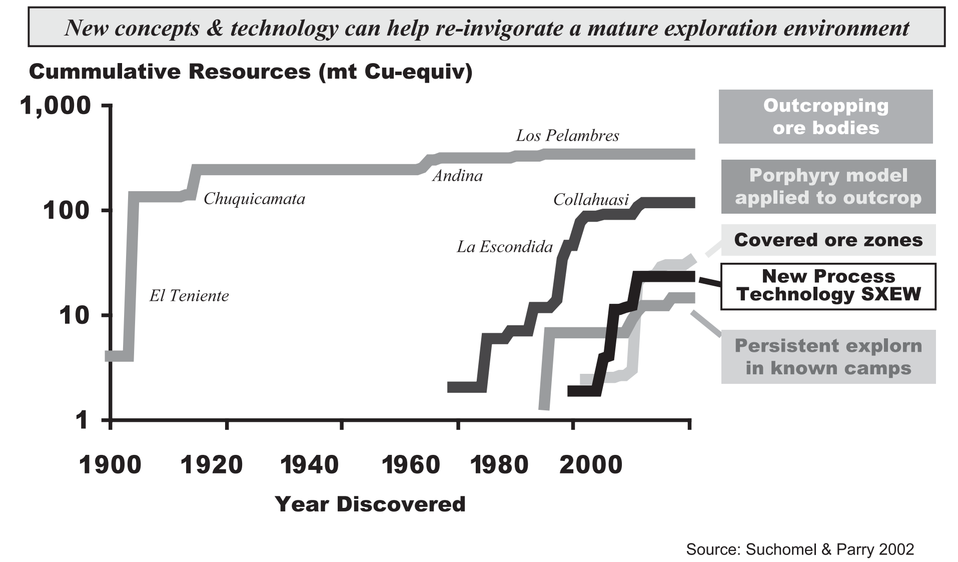


FIGURE 5 Cumulative number of tonnes of copper metal found in Chile using different technologies and exploration concepts, 1900–2000

1. The time scale for developing this type of technology is more like 20 years than the 3–5 years typically assigned for the initial campaign, and patience runs out.
2. For successful development there is no way of avoiding a large, expensive pilot-plant phase.
3. If the underlying motivation is not both strategic and strong enough to counterbalance the risk and cost of the exercise, don't do it.

R&D Strategy

The A D Little book, *Third generation R&D* (Roussel et al. 1991) had a major influence on large company approaches to the management of technology. At that time most research and development undertaken by minerals companies either internally or by contract was short term and *ad hoc*. It was rarely undertaken within the context of a technology strategy, which, in turn, ought to have been part of the company's business strategy. During the mid-1990s, as attention switched to developing a portfolio of projects closely aligned to the business, large mining houses went about major downsizing of their technological and exploration efforts. For example, BHP and Rio Tinto both closed major in-house laboratories; Alcoa reduced staff in its Pittsburgh complex. Exploration groups in BHP, Rio Tinto, WMC and many others were significantly cut back.

But smaller may mean smarter. At least now there is significant alignment of exploration and technology strategies with the company business strategy. Companies, facing rising costs, are shifting to improvements addressing short-term needs and brownfields expansions at the expense of greenfields exploration or development. In today's environment, most minerals companies have a clear strategy for technology, even if this is to focus on the short term. Such a technology strategy requires a clear understanding of the

company's core competencies and core technologies, an objective assessment of the company's competitive position in those competencies and technologies, and strategies for maintaining and enhancing these capabilities preferably under a portfolio management approach. The risk is that a short-term approach does not create opportunities to develop major new businesses for the company.

Most importantly, indeed probably the single most important factor for successful technology management is the commitment from the senior management of the company.

Three Horizons for R&D

Three horizons of company growth can be defined (Baghai, Coley, and White 1999): Horizon 1, extending and defending core businesses; Horizon 2, building emerging businesses; and Horizon 3, creating viable options. The authors argue that all three horizons must be managed and that each requires a different focus and performance measure. How minerals companies do this in a market of stagnant size is a matter of conjecture.

Companies will range across these three horizons in terms of emphasis/expenditure, strategy and structure. In 2001, WMC undertook a survey of technology development within a peer group of mining companies. Some companies indicated a prime focus on incremental improvement (Horizon 1) and were unlikely to sink large capital into speculative projects. However, others were willing to make significant commitments to step change projects (Horizon 3) on the basis of achieving significant competitive advantage. For example, BHP Billiton has invested heavily in airborne gravity gradiometry (Falcon) and biotechnology (BioNIC, BioCOP, etc). Rio Tinto, in addition to significant investment in direct iron making (HIsmelt), saw their competitive advantage in the rapid identification and adoption of emerging technologies and the effective transfer across the operations.

It is not necessarily only the big players who are making breakthroughs, for example, Phelps Dodge in heap leaching of low-grade copper ores, Inco in nickel carbonyl technology and WMC in the application of automated underground vehicles.

There have been many changes in how companies structured their technical effort over the last 30 years. Rubenstein suggests that these are "not always in the direction of improving effectiveness of the R&D/innovation and not always to the benefit of the firm" and may be more influenced by the boom-bust economic cycles. However, a rational approach based on the three horizons for growth would be to structure and manage technical developments according to the strategic emphasis placed by the company management on each horizon, its size and available resources and the "life" of their deposits.

In addition to the strategic positioning taken by the company in their markets, the key determinants for internal technical delivery ought to be (i) the size and extent of the operational activities and whether these cover one or several commodities, (ii) the nature of each commodity market and the extent of vertical integration within the company and (iii) technological complexity associated with the commodities.

The pressures created by the operational structure of the business can have important influences on the technology function. For example:

- Operational unit task orientation towards "return on capital" and simple "cost reduction" targets unduly discourages spending on technology support and development.

- Short-term time horizons in business plans and excessive focus on current year budgets can impact on the long-term creation potential of technology development.
- The tendency for business unit structures to inhibit “share support” and cross-unit technical transfer.
- The remoteness of some operational sites and efficacy of internal career path development will affect the ability to retain and motivate technologists.

More important than structure is the processes by which the technology function is driven by the company’s strategic plan and business imperatives and how it is efficiently managed to maximise potential gains across the three horizons.

GETTING AND RETAINING TALENT

In Australia, the Minerals Tertiary Educational Council has expressed concerns over the declining numbers entering tertiary institutions in traditional mining/minerals industry related disciplines. Whilst numbers entering the profession have a stochastic character and company operational efficiencies have reduced demand, the Council predicts that significantly reduced numbers of mining and metallurgy graduates and post-graduates will be available to enter the workforce over the next few years.

In Australia, competition for funds within the University system has placed great strains on small departments whose student numbers fail to reach funding quotas. If the industry is not careful, we will wake up some day and find that all university departments of metallurgy and mining are gone.

However, of potentially greater concern to the minerals industry, as well as most other technology-based industries, is the significant decline in the quality of science education and learning within the secondary schools system in Australia. This is a worrying trend, as Australia with South Africa, USA and Canada represent a significant proportion of the graduate base entering the minerals industry.

If recruitment trends continue and the market forces do not reverse the availability of supply, most companies will need to grapple with recruiting and retaining key technical talent. In 1997, Woodall (1997) in his keynote address to the AMIRA Conference outlined the common links in the chain of intelligent management, which are fundamental to remaining profitable:

> *The links in the chain are effective interdisciplinary communication, knowledge, vigilance, motivation, trust, perseverance, professional leadership, teamwork, vision, freedom, delegation and a caring management.*

With the predicted tightening of the supply of new talent, a company’s ability to successfully undertake these linkages will be severely tested.

CONCLUDING REMARKS

Looking back some 40 years one can see nothing but change, changes mostly for the better. Solutions to challenges arising from such change have required greater ingenuity with time. These challenges have been met by adaptation.

Technologists and their managers have a better understanding of the company’s needs; they are better prepared with the management and technical tools to develop

different solutions; knowledge management tools and the computer has connected them to a plethora of resources.

But the industry is lagging in the competition for talent. It is not engaging sufficiently in the debate which channels key government resources into education and research institutions; it is too willing to sit back. When the crisis caused by the lack of capability emerges, recovering the situation will be long and painful as high-class educational institutions, which give birth to such talent, take years to develop.

If the industry addresses this issue, it will have the talent to continue, maybe accelerate innovation in the mining and minerals industry to the benefit of our shareholders and the community.

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Minimization of Delays in Plant Startups

Terry P. McNulty*

During the last 30 years, at least ten authors have dealt with startup ("ramp-up") times for minerals beneficiation, hydrometallurgical, and/or pyrometallurgical plants. Most have attempted to identity the reasons for delays and some have suggested attributes common to successful startups, as well as those shared by unsuccessful ones. The most recent has advanced a project characterization matrix as a predictive tool for qualified users. This paper will summarize past work, will review cause and effect, will outline an approach for refining our ability to avoid costly delays, and will seek guidance from professionals most likely to use such a tool.

INTRODUCTION

During the last few decades, many billions of dollars have been lost by investors in mineral industry projects that did not perform as well as their developers had hoped. The most common form of failure has been the inability to generate a profit quickly, and delayed achievement of planned production rate has been the chief cause. Minerals processing projects are by no means the only kind of plant to suffer from startup delays, as some authors cited in this paper considered inorganic chemical plants and other types of facilities. Furthermore, mines are not without fault and there have been many that were closed after years of disappointing performance. However, our interests as a group are most sharply focused on mineral processing and our database for such projects is relatively extensive. It is sufficient to say that the conclusions made or repeated in the following text can be readily extended to most types of projects.

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SUMMARY OF PREVIOUS PAPERS

Merrow et al. (1981), with The Rand Corporation, published a series of reports for the U.S. Department of Energy (DOE). The primary motivation for DOE's interest in financing these studies was a need to understand the economic risks related to various proposed alternative energy projects including exploitation of oil shale. The Rand studies were concerned primarily with risks attendant to adoption of innovative technology, but they broadened the meaning of "innovation" sufficiently to allow formation of broad conclusions applicable to many kinds of projects. Their case histories were drawn from the 1970s, a decade of many first-of-a-kind projects based on complex flowsheets and built to heroic scale. They concluded that risk of project failure (measured by major cost overrun or failure to achieve nameplate capacity within several years) was sharply increased if (1) insufficient effort was devoted to understanding process chemistry, (2) insufficient continuous pilot-scale testing was conducted, (3) the plant lacked parallel process streams and/or in-line spare equipment units, and (4) the design incorporated sequential unit operations that either were first-of-a-kind or the largest ever built or both.

Charles River Associates was engaged by The World Bank to study 250 projects constructed during the period 1965–1978. Agarwal and Katrak (1983) selected 53 of these projects on the basis of (l) a balance between developing and developed nations, (2) vertically integrated versus stand-alone, (3) mixed as to metal product, and (4) varied as to geography and climate. Mills and concentrators generally failed to reach 100 percent of design feed rate until the second year. New mines suffered from poor planning. About half of the smelters averaged less than 70 percent through the third year and some failed to achieve 100 percent after 4 years. Since the late 1970s and early 1980s were plagued by extraordinarily high interest rates in the range of 12–18 percent, the time value of money was a crucial factor in the financial outcome of a project. Even now, though, with very low interest and inflation rates, the first year in a processing plant's life usually has the greatest impact on project success.

In a companion paper, Agarwal et al. (1984) repeated the contents of the earlier article and added a section on project planning and preparation. They concluded that a logical systematic management approach to preparing the owner's organization for startup must begin early in the project's life cycle and should include the following elements:

- Work plan, schedule, organizational structure, and budge
- Programs for pre-operational testing and training
- Operating manuals
- Management and control procedures
- Startup problem-solving task forces.

McNulty (1998) considered 41 processing plants that had been built on the basis of levels of technological innovation ranging from mature to first-ever. He set out with a suspicion that more innovative processes would require longer startup periods. However, reduction of the data and a grouping according to common project characteristics such as proven design, unusually aggressive process conditions, poorly understood ore mineralogy, or overly promotional owners revealed that innovative technology, *per se,* played a relatively minor role in determining startup profile. The real issue was the care with which the technology was developed and implemented. McNulty expressed plant

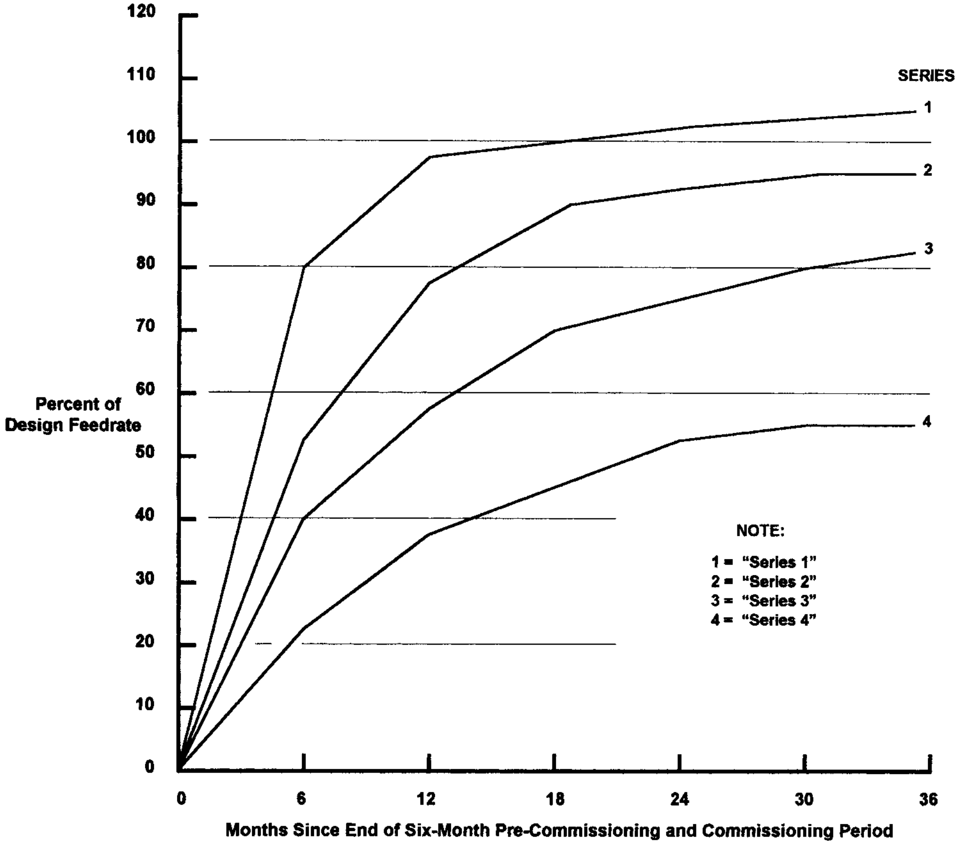

FIGURE 1 Rate of achievement of design feedrate

performance as Merrow did, percent of design *feed rate* versus time since the end of commissioning or the beginning of startup. If this distinction could not be determined, time zero was taken as 6 months after the end of construction. Data were then averaged, allowing separation into a family of four curves as shown in Figure 1. The Series 1 projects had the most rapid startups and Series 4 had the slowest. Although two Series 1 projects achieved 100 percent of design within 6 months, the average for that series was 18 months.

Nendick (2002) described how proper project organization and execution can help the project's owner avoid delays and minimize risk. He began with an explanation of the structure of a good contract embodying definitions of plant performance, a precise description of the plant performance test and its objectives, and an assignment of responsibilities for each stage of the project. He then discussed engineering, commissioning plans, ramp-up, and the performance test itself stressing the importance of good record keeping throughout each stage of the project. He emphasized the importance of having good people, of being diligent about planning, and of nurturing a strong spirit of cooperation among all project personnel. He discussed McNulty's set of four performance curves,

but added a Series S that illustrated a recent very slow ramp-up that eventually exceeded Series 4 behavior.

Mackey and Nesset (2003) introduced the criterion of cumulative plant *output* versus time and applied that concept to nine projects completed during the late 1990s. For their purposes, plants sharing Series 1 and Series 2 characteristics were considered together, as were those sharing Series 3 and Series 4 characteristics. Representing Series 1 and 2 were three copper or copper/gold mines and mills (Ernest Henry, Collahuasi, and Batu Hijau), the Century lead/zinc mine and mill, the Gresik copper smelter and refinery expansion, and Kennecott's 1995 copper smelter and refinery modernization. Those projects showing Series 3 and 4 behavior were three pressure acid leach (PAL) lateritic nickel plants (Cawse, Bulong, and Murrin-Murrin).

Ernest Henry nearly achieved Series 1 behavior in terms of feed rate, but was between Series I and 2 for copper production. Collahuasi exceeded Series 1 for electrowon copper cathode production, but was between Series 1 and 2 for concentrate production. Others in the group were typically between Series 1 and Series 2 for feed rate and production, although Kennecott's project was Series 2 for feed rate and Series 4 for production during the first 2 years. Mackey and Nesset also analyzed the compounding of decreased plant operability by the number of unit operations in series, illustrating the disadvantage of complex single-train design. They concluded with an analysis of the impact of startup delays on project financial performance and left no doubt that there is a great incentive for careful data collection and validation, good planning, and good staffing and training.

Nice (2003) reviewed previous studies and analyzed seven recent projects in Australia and Australasia. Like Mackey and Nesset, he plotted rate of achievement of design metal production and found that the ramp-up profiles corresponded well with the conclusions of Agarwal and Katrak and with the family of four curves presented by McNulty. He observed that "...we in industry do not appear to have learned much from history" and stated that we now have very accurate mass and heat balance modeling capabilities, powerful design tools, better materials of construction, and more reliable equipment, yet our projects fail for the same reasons that caused them to fail during the 1960s.

Twigge-Molecey (2003) advocated a disciplined approach to risk management if we want to maximize the profitability of our projects. He emphasized technological and capital risks and made many important points. He differentiated technology classifications ranging from Type 1, well proven at similar plant settings and scale, to Type 4, new technology being implemented for the first time. Turnkey fixed price contracts, he noted, are a major risk for all but Type 1 technology and will lead to problems with all other types, especially with a "fast track" schedule. His summary of the negative aspects of a turnkey contract is useful:

- The risks must be managed by those with the appropriate expertise, normally not the construction contractor.
- The ultimate risk always lies with the project's owner.
- Turnkey fixed price contracting gives the contractor an incentive to economize at the expense of the project's operating and maintenance costs.

Twigge-Molecey concluded his paper with a persuasive argument that mining organizations and the firms providing services to them rely on knowledge for successful projects and sustainable operations. Especially in the U.S. and Canada, skilled engineers are, on

average, near retirement age with few mechanisms in place for systematic replacement of the attendant intellectual loss.

Vancas (2003) analyzed the accuracy and reliability of feasibility studies and quotes others who have made similar analyses. Whereas most feasibility studies prepared for financing purposes are expected to be accurate within 5 percent, the consensus is that only about 40 percent lie within this range. One analyst studied 60 projects and found that only 15 were completed underbudget. With specific reference to project organization and management, Vancas emphasized the importance of clear scope definition, good communications, team qualifications, stability, and diligent project control.

Halbe (2003) discussed some of the conclusions previously cited in this paper, then went on to present a simplified financial analysis (using a discount rate of 8 percent) of McNulty's Series IA project startup profiles for a hypothetical gold hydrometallurgical plant. His results were as follows:

Startup Profile	Net Present Value
Series 1	\$209 million
Series 2	\$110 million
Series 3	–\$25 million
Series 4	–\$240 million

Clearly, startup performance has a profound effect on the financial success of a project. Halbe then pointed out that there seems to be unanimity about the frequency and nature of failed projects and causes of those failures, but we have all concentrated on postmortems. He asked rhetorically, "How about learning from our mistakes?" His response was to suggest a project characterization matrix that could be used to rank a project according to a list of criteria. An experienced professional could then make an objective assessment of a project's likelihood of success at any point in its development. Most importantly, potential weaknesses could be identified in time to save the project or to prevent investors from making an expensive mistake.

SPECTRUM OF STARTUP PROFILES

Figure 1 is a composite of the startup patterns of 41 greenfields projects and does not fairly represent the extremes of behavior—the very quick and the complete failures. Some projects—and gold CIP plants as well as copper solvent extraction/electrowinning operations are good examples—have reached design capacity in a few weeks without pilot testing. Others have failed to reach a significant feed rate and were eventually closed and abandoned. Forgetting about those, it is probably safe to say that nearly all other types of projects are going to fall within an envelope defined by curves that are about 20 percent faster that Series 1 and 20 percent slower than Series 4. Figure 2 depicts this envelope, and nearly all of the startup profiles presented by the authors cited earlier fall within it.

CAUSE AND EFFECT

Among the characteristics shared by projects within a given series, the following are pervasive:

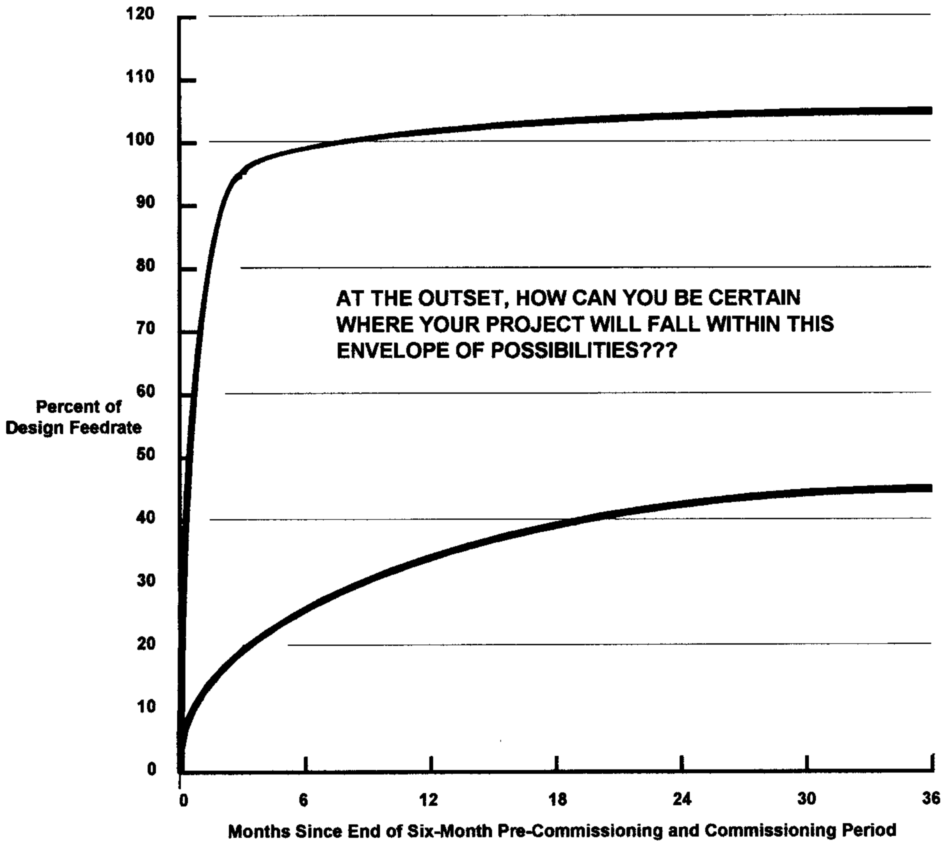

FIGURE 2 Rate of achievement of design feed-rate spectrum of startup profiles

Series 1

- The owners relied on mature technology.
- Standard types of equipment were selected.
- Thorough pilot-scale testing was done on potentially risky unit operations.

Series 2

- If the technology was licensed, the project was one of the first licensees.
- Some equipment was prototype in size or application.
- Pilot-scale testing was incomplete or was conducted on non-representative samples.
- Process conditions were unusually severe or corrosive.
- Non-innovative parts of the flowsheet received inadequate attention.

Series 3

- There was very limited pilot-scale testing and important steps were ignored.
- Feed characteristics such as mineralogy were poorly understood.
- During process development, product quality received little attention.
- There were serious design flaws.
- Engineering, design, and construction were on a "fast track" with inadequate planning to offset added risk.

Series 4

- If continuous tests were run, they were only to make product.
- Equipment was downsized or design criteria were compromised to reduce cost overruns.
- The flowsheet was unusually complex with prototype equipment in two or more unit operations.
- Process chemistry was poorly understood.

There were additional characteristics shared by many of the Series 2, 3, and 4 projects:

- Corporate management had a promotional or overly aggressive attitude.
- The owners had very little day-to-day engineering input.
- Driving forces underlying the project were ill-conceived.
- Unanticipated increases occurred in costs of consumables.
- Product prices declined unexpectedly.
- The ore receiving and preparation areas received little attention.
- Hands-on training of the workforce was inadequate.
- Training manuals were inadequate or non-existent.
- Translation of the testwork to design criteria was flawed.
- The supervisory staff was inexperienced.
- Materials of construction were incorrectly specified.
- Technical support during commissioning and startup was inadequate.
- There were serious engineering deficiencies.
- Safety margins, if applied at all, were inadequate.

WHERE NOW?

Everyone involved in a project wants it to succeed. Officers in the corporate owner want to succeed personally and want their company to prosper. Directors of that company have a fiduciary responsibility to its shareholders. Officers of lending agencies want performing loans. Buyers of the product are depending on a supply. Project managers want to get the job done and hope to be recognized for successful completion.

The authors cited in this paper have clearly stated the steps that must be taken to make a project perform well. Obviously, there are unforeseen problems, but risk from known factors can be minimized. What are we as mineral processing practitioners going

to do about it? Doug Halbe has suggested a tool that could be used by an experienced professional to predict success and to identify effective remedial measures. Development of this project characterization matrix will require data, suggestions, and advice from our colleagues in the mineral processing community. We look forward to continuing to work with those colleagues on refinement of an improved project management and investment decision-making technique.

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How to Sell R&D in Your Organization—Without Begging

Steven A. Elmquist*

INTRODUCTION

R&D activities are needed, at a minimum, for a company's competitive survival followed in importance by the growth and diversification of the company. For most industrial companies, however, R&D is the business area that has been the most difficult relative to confident long-range financial commitments and effective control and relative to its value as a long-term investment. Investors look not only at the current profitability of the company but increasingly at the plans, actions, and quality of the personnel in position to improve the market position and profitability of an organization. "The strongest predictor of investment value is the degree of innovation of the 'company.' I believe this is true of both strategic planning and R&D activities." R&D is the lifeblood of a company's future.

If this basic premise—R&D for survival and growth—is believed to be true, why is it necessary to "Sell R&D" in your organization? My personal experience, in a number of organizations, is that R&D budget is perceived as a business element area that could be delayed or reduced to improve the bottom line during difficult business conditions. I believe the following quote speaks volumes about this subject—"There is only one thing I know for certain about research, and that is it costs money—lots of it." —Unnamed, Hardheaded Financial Executive.

A business must make money and be profitable in order to maintain and create jobs, pay taxes, cover working capital and costs of goods sold, and most importantly, create value for its shareholders. The foremost element of selling R&D, therefore, is to consistently demonstrate the R&D group's contribution to the bottom line.

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OBJECTIVES BASED ON CORPORATE STRATEGY

Knowledge and understanding of corporate strategic direction and objectives is the first step in selling R&D to your organization. Senior management's communication to technical and research personnel about these objectives is critical to the R&D/Technical personnel planning process. Without knowledge of the desired corporate direction, an accurate assessment of existing versus required resources is not possible. Resources are facilities, equipment, support personnel, outside agencies and internal personnel. Technical personnel capabilities should be reviewed to determine if they match the perceived capabilities required to achieve the corporate strategic objectives. It is critical that personnel skill sets and aptitudes match the forward-looking strategic objectives. Training for existing personnel is required to prevent obsolescence of skill sets. New employee recruitment and hiring should be structured to provide the balance of talents required to meet the strategic objectives. It is important that "you get the right people on the right seats in the bus." (1)

DEFINE/RECOGNIZE YOUR CUSTOMER

Selling a product or service requires a customer(s). R&D personnel should realize they have many "customers" within their organization. These customers include the senior management team, commercial and sales representatives, and the group with probably the most direct impact and influence—the operations or manufacturing group. Outside their organization, they often interface with the corporation's product consumers (customers) in a technical or sales support role. R&D personnel must recognize their customers and develop personal relationships that will help merge R&D project development into the corporate strategic plan. Communication and interface with the various customers, relative to ongoing and future R&D investigations, is key to having a dynamic flexible R&D program. The feedback R&D personnel obtains from this customer should provide guidance for R&D planning, in association with corporate strategic goals. Proper communication will result in an R&D project plan having "Buy In" from at least one of the customer groups.

SHARED SUCCESSES

Development of personnel relationships is key to promoting the R&D project plan. Shared successes are the acknowledgment of a team effort between R&D personnel and, typically, plant operations staff. Shared success can, however, occur in all the various customer segments. Independent of the idea origin source, R&D personnel must promote shared success if they expect long-term cooperation with plant operations and other customer groups.

The team-building concept is not a recent revelation to business and organization. Some useful team-building methods include Rapport International Leadership, General Electric's CAP's process and others such as the Center for Creative Leadership. These techniques provide focus to a diversified group and ultimately develop the communication and trust needed to develop collaborative relationships.

Progress reports on a consistent and timely basis will assist the team-building process through demonstration of individual personal accountability and professional proficiency. It is important that the reporting frequency is designed to keep all interested parties informed to the level that "sudden project success/failure" is not a complete surprise. No level of management wants the embarrassment of being blindsided. Avoid the "Pollyanna

Syndrome"—this being that all news that is presented is delivered in a good news delivery pattern, which leaves out the questionable aspects of the project's progress or anticipated results. Project reporting should be accurate, honest and not biased by personal involvement or prejudice. An individual's ability to terminate a poor project or halt a project for redirection will build the confidence and credibility needed in a team-based environment. Avoid " Project Go Fever" if you wish to maintain long-term organizational credibility.

PROJECT SELECTION

The three basic phases in establishing R&D projects are

1. Obtaining the ideas and developing concrete proposals
2. Evaluating the ideas
3. Final selection of projects which have met the requirements and have the best chance for economic success.

These simplistic statements do not truly express the effort required to select, implement, and produce a successful research project. Members of our organization have attended a number of seminars related to methodologies and metrics that can be used to develop a project selection process. We ultimately selected a project selection and justification process called the Stage Gate Process (2). The following stages are used in a fairly regimented approach.

1. Stage 1, Idea—Create ideas for new research and development projects.
2. Stage 2, Initial Investigation—Determine whether an idea merits becoming a research project.
3. Stage 3, R&D Project Proposal—Develop a detailed proposal for the project.
4. Stage 4, R&D Project—Provide a complete and final evaluation of the entire project minimizing commercial and technical risk.
5. Stage 5, Implementation Plan and Formal Approval—Prepare plan for full-scale implementation including goals and milestones.
6. Stage 6, Installation and Audit—Complete action plan and realize economic benefits.

The many subset points to each of these categories are shown in Figure 1.

Our experience has shown that this process works well in developing participation from the various customer groups throughout our organization. The basic flaw in our process occurs in Stage 4. We have developed an evaluation matrix that generates a numeric rating by considering items such as probability of project success, length of time to commercialization, probability of developing a proprietary property, project cost, and the magnitude of financial reward. The issue we are working to resolve is the lack of significant differential in final numeric rating between multiple projects. Several attempts have been made by the project evaluation committee to adjust the weighting system to obtain a more significant difference between projects. To date, we have not been able to develop a solution and have had to select projects based on the rating system numeric value coupled with a general consensus on which projects make the most sense for our company. It is apparent that the different customer groups have a slightly different perspective on what is important in the evaluation matrix. This is, however, an unanticipated side benefit to this process as the discussion created results in a broadening of the overall group's understanding of the issues important in our organization.

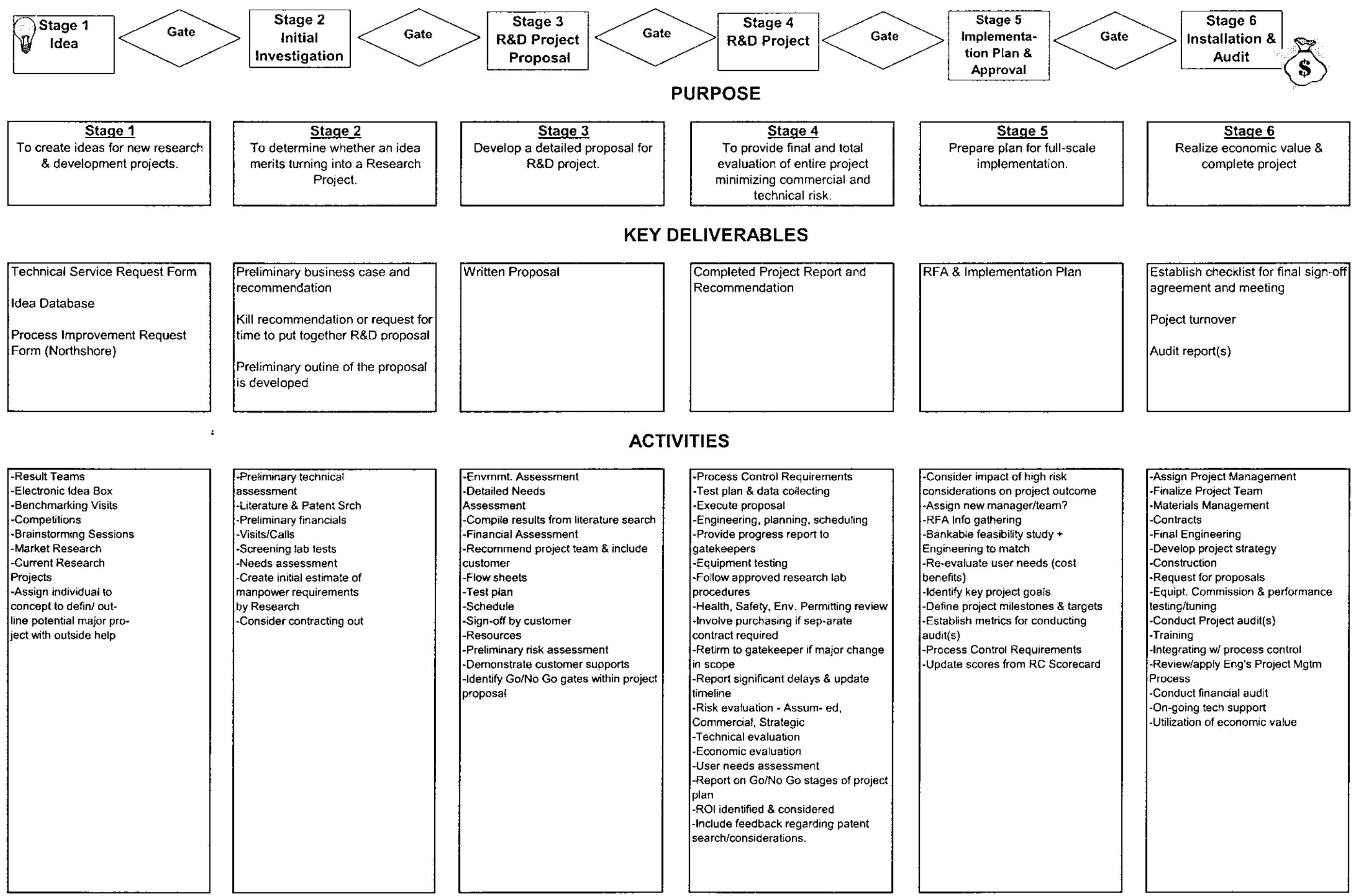

FIGURE 1 Cleveland-Cliffs' stage gate process

DEFINE THE PROCESS BOTTLENECKS—REINVENTION VERSUS CAPITAL

"Development (Research) is to see what everybody else has seen and to think what nobody else has thought." —Dr. Albert Szent-Grjörgi—Nobel Prize Winner (3). I believe the "D" part of R&D has taken a more significant role in companies due to the difficulties in obtaining the funding required for major plant or process modifications. The improvement of plant process and operations via modification of the existing plant unit operations is a key role of an R&D technical/process group. The importance of plant or process audits cannot be overstated as upgrades or changes available for existing process equipment, or the economics of other elements that affect circuit performance, are not easily recognized in the daily operational mode. These audits can identify system bottlenecks which, when solved, can create another bottleneck in the system. The circular analysis resulting from the shifting of process bottlenecks requires close communication with plant personnel in order to smoothly transition from improvement to improvement without process disruptions. The working relationships (and trust) developed during this improvement process will assist in obtaining support for an R&D project which, though less defined in future benefits, have potential of reducing the plant operating costs assisting in business growth.

R&D STAFF—THE BUSINESS SIDE

It is easy for an R&D technical professional to become focused on solving the technical issues and opportunities that seem to present themselves on a daily basis. It is necessary for all technically focused personnel to have an understanding of basic business financial indicators/metrics. In addition, they must be knowledgeable about the corporate financial status, key process indicators and key operating variables, product line and process systems functions and system bottlenecks/opportunities. It will be easier to sell the R&D function in your company if your customers are aware that you make financial decisions (i.e., spending money) based on the probability of making a designated rate of return.

SUMMARY

In order for an R&D organization to be effective it must incorporate the Corporate Business Strategy, contribute to the profitability of the organization, define and have available the necessary resources, develop strong relationships with the various customer bases, select projects based on corporate objectives and financial benefit, maximize operations efficiency with minimal capital, and demonstrate good business sense when utilizing corporate resources. Business is about people and relationships that generate trust through open, honest communication and shared success.

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Technology Development and Competitive Advantage: Sustainable or Short Term?

John O. Marsden*

Technology development has played a crucial role in the minerals industry throughout history. The development of new technology allows mankind to produce metals and minerals at progressively lower cost of production in real terms, and therefore at progressively lower prices, improving their availability, accessibility and utilization worldwide. However, the developers of such technology are not guaranteed to reap the benefits from this effort: There is an expectation that technology developers will gain an advantage over their competitors. Is this a short-term benefit that results from a temporary cost or efficiency improvement, or is it a sustainable longer term "edge" that prevails even after metal or mineral price has been eroded by the implementation of a major step change technology? This issue is examined by reference to several case study examples in the copper industry.

BACKGROUND

The development and adoption of new technology has played a crucial role in the commodity minerals industry throughout history. As new, cost-efficient technologies are commercialized, the cost of production decreases, and this enables lower grade ore to be processed profitably. This in turn increases the availability and supply of the metal or mineral of interest, and ultimately (in a free market environment where the supply-demand balance determines price) inevitably decreases the metal or mineral price. This leads to the question: Why should mining companies invest in (new) technology development if the result is a decrease in the product price? The answer is to achieve competitive advantage, where the application of new technology enables one or more

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commodity producers to gain a cost advantage over their competitors, at least for a period of time. The more sustainable and longer term, the greater the competitive edge achieved.

Technology development is costly and, in general, the greater the potential benefit, the higher the cost. The commercial implementation of new technology is inherently risky—the technology has not been applied before and must be proven over time. The risk must be managed, and this involves additional cost and intellectual effort. Finally, both technology development and commercial implementation typically requires significant investment of time. This latter factor is significant where the metal/mineral of interest is a commodity that exhibits cyclical pricing with extended periods of depressed pricing followed by periods of strong pricing. This will be discussed further later.

SOURCES OF COMPETITIVE ADVANTAGE

There are many sources of competitive advantage that can result from the development and application of new technology. Each of these is listed and briefly reviewed below:

1. Prevent competitors from using the technology

The mining industry is well-accustomed to the use of patenting of technology, processes, equipment, chemicals and reagents, non-commodity supplies, and other aspects of the mining industry. Patents can provide companies with an effective way to protect competitive technology for a significant period, up to twenty (20) years. In addition, the ability to maintain technical know-how, operational expertise and trade secrets as confidential and proprietary information is an alternative (or complimentary) way to protect competitive technology in both the short and long term.

2. Make it hard for competitors to use or duplicate the technology

In some cases, maintaining technical know-how, operational expertise and trade secrets as confidential and proprietary information may be a successful strategy in achieving competitive advantage. The downside with this option is that it is difficult to keep such information as truly confidential and proprietary for a significant period of time. In addition, such a strategy stifles technical and operational interchange between mining operations and companies, and this approach is probably unproductive in the long term.

3. Apply the technology more rapidly than competitors

Being the first to apply a particular technology cost effectively, to rapidly improve the technology, and quickly make a significant impact on a substantial proportion of overall production and costs may provide significant competitive advantage. Alternatively being a "fast follower" or a rapid adapter of technology may provide similar benefits.

4. Apply the technology better than competitors

If you apply a particular technology better than your competitors, either with greater efficiency, at a larger scale, or at lower cost (capital or operating), then competitive advantage may be achieved. A company's ability to do this depends largely on the quality of people and the resources at their disposal to effectively apply technology and

innovate within their operations. As a practical matter, it is difficult to achieve sustained competitive advantage by this manner alone because of the mobility of staff (much greater in recent years than historically) and the relatively rapid and free interchange of information throughout the mining industry.

5. Apply the technology to a greater proportion of metal production than competitors

If a technology can be applied broadly across multiple operations or divisions within a company, it is likely to be more advantageous than its application at a single operation by a competitor. For example, a company that can effectively apply a new nickel laterite hydrometallurgical process to 50% of their mineral reserves will derive greater advantage than a similarly sized company that applies the same process to only 5% of their reserves.

6. Derive more value than competitors due to specific geographical, geological or other conditions

One company may have specific geographical or geological factors or other site-specific conditions that renders the application of a particular technology to be more favorable at one or more of their sites than for others. This can be a source of sustained competitive advantage. An example might be a blend of potential acid-producing mineral resources located close to acid-consuming mineral resources that can utilize a technology that produces acid as a by-product.

7. People development and motivation

Technology development activity excites, invigorates and motivates capable and energetic technical and operating people. Technology development activity gives staff the opportunity to get involved in something new and to create value out of nothing, purely through innovation. This environment gives staff the chance to grow along with the technology being developed. Technology development breeds a contagious enthusiasm—a commodity that can't be easily bought or traded.

TECHNOLOGY DEVELOPMENT AND IMPLEMENTATION

The "players" in the implementation of new technology fall into four categories, as follows:

"First Mover"

The first mover has the highest risk in applying a new technology, and generally the highest cost. However, there is the potential to apply the technology rapidly and leverage the technology with competitors to gain advantage. The first mover has the potential to reap the largest benefits and, potentially, a sustained competitive advantage.

"Fast Follower" (or Adapter)

The fast follower gains the benefit of the "first mover" experience with the implementation of a new technology. The fast follower or adapter has lower risk compared with the first mover, but risk may still be high because some aspects of the technology may not be

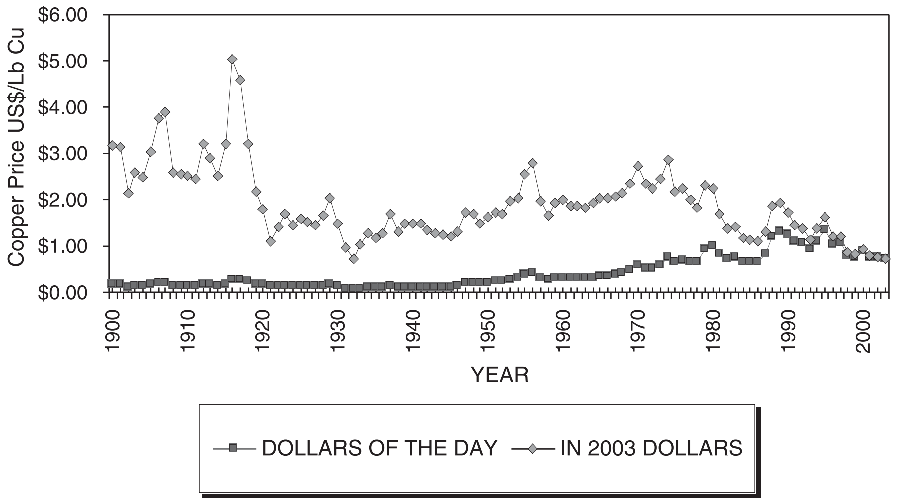

FIGURE 1 Annual copper price between 1900 and 2003

fully proven. There may be some potential for the fast follower to leverage the technology and gain significant competitive advantage. In some cases, there may be an ability to gain greater competitive advantage than the first mover as a result of lessons learned.

"Conservative Follower"

The conservative follower takes a low-risk approach, but does whatever needed to stay competitive over the long term, even if the benefits may not be achieved from the technology during its initial period of application. The conservative follower has little opportunity to leverage the technology to achieve competitive advantage and may end up as the one being leveraged.

"Lagger"

The lagger takes the lowest risk option at every opportunity and stays with well-proven technology. They are the last to adopt and apply new technologies, but rely on other ways to stay competitive (e.g., resource quality, captive market or integrated market) or end up exiting the market voluntarily or involuntarily.

CASE STUDY: TECHNOLOGY DEVELOPMENT IN THE COPPER INDUSTRY

The Copper Price Cycle

Let us consider the example of technology development in the copper industry throughout the 20th century. Figure 1 shows the annual average copper price from 1900 to 2003, with the price expressed in constant 2003 dollars. The period is characterized by peaks and valleys that reflect the market forces for the commodity traded in the western world and, more recently, on a more global basis. During periods where demand has

TABLE 1 Periods of increasing copper price

Period	No. of Years
1902–1907	5
1911–1916 (Beginning of 1st World War)	5
1921–1929	8
1932–1937 (Post-depression)	5
1945–1956 (Post-2nd World War)	11
1958–1970	2
1986–1989	3
1993–1995	2
Total	41

TABLE 2 Periods of decreasing copper price

Period	No. of Years
1900–1902	2
1907–1911	4
1916–1921	5
1929–1932	3
1937–1945	8
1956–1958	2
1970–1986	16
1989–1993	4
1995–2003	8
Total	52

outpaced supply, the peaks occur. Conversely during periods where copper supply exceeds demand, then periods of low price prevail. In general terms, peaks have occurred in 1907, 1912, 1916, 1929, 1937, 1947–48, 1956, 1970, 1974, 1979–80, 1989, and 1995. Similarly, valley "troughs" have occurred in 1911, 1914, 1921, 1932, 1945, 1958, 1972, 1978, 1986, 1993 and 2002.

During the period 1900–2003 shown in Figure 1 (103 years), there have been approximately 9 major price cycles. Table 1 shows the major periods of increasing copper price.

Without exception, these periods of increasing price are related to strong copper demand and consumption, low production (either slow recovery of curtailed production and/or insufficient new production brought onstream to keep pace with demand), or combinations of the two.

Table 2 lists periods of decreasing copper price.

The periods of decreasing price are related to 1) periods of weak copper demand, with excess copper going into exchange inventories or other easily accessible inventories, 2) excessive copper production, either due to slow curtailment of production during a copper cycle downturn or too much new production brought on line in excess of demand requirements during the peak period of the copper price cycle and, as some have postulated, 3) technology developments that increase production and/or lower the cost of production significantly and on a sustained basis.

While there is no doubt that the supply-demand balance drives the copper price, the question of whether significant technology development adversely affects the copper price is more complex. This issue will be examined further using three examples of step change technology development in the copper industry: open pit "bulk" mining, flotation, and solvent extraction-electrowinning (SX/EW).

Large Scale (Bulk) Open Pit Mining

The widespread adoption of bulk, open pit mining methods in the 1920s and 1930s represented a significant technology development for the copper industry. During the period from 1910 to 1945 there were significant increases in ore milling rates, in large part made possible by the bulk open pit mining method. According to A.B. Parsons, Daniel C. Jackling first proposed the use of large-scale, bulk, open pit mining at Utah Copper in 1899. His proposal was based on mining 2,000 tons per day of ore. At the time his proposal was made, the largest copper concentrator was 500 tons per day, so his proposal represented a "stretch" for both mining and processing technology. In 1905, Utah Copper made the decision to proceed with the open pit plan and production started in 1907.(1) It may seem obvious to us now that open pit "bulk" mining makes good economic sense, but at the time this was far from obvious and intuitive. Utah Copper was milling almost 15,000 tons per day by 1910, increasing to 25,000 tpd in 1913 and to about 75,000 tons per day by 1940.(2,4) By contrast, Morenci began large-scale mining in 1942, supplying ore to a 25,000-tons-per-day concentrator, which was increased to over 40,000 tons per day by 1947. El Teniente (originally "Braden") was processing only 6,000 tons per day of ore prior to 1920, but increased to 15,000 tons per day by 1927, and then to about 30,000 tons per day by 1947. Open pit mining started at Inspiration in 1948 and at Ray in 1950. Large-scale open pit mining started at Chuquicamata in about 1927 at a rate of more than 20,000 tons per day and increased to about 50,000 tons per day by 1952.(2) This chronology indicates that many companies were slow to adopt open pit mining methods, even though this ultimately proved to be the most effective mining method.

The above discussion indicates that the major copper producing (porphyry) mines increased ore mining and processing rates dramatically between about 1925 and 1947, with the majority of the major expansions occurring between 1940 and 1947. By 1947, 73% of the US copper production was obtained by open pit mining.(6) Similar developments in Chile followed. As open pit mining took off, the increased scales of economy for the bulk mining and significantly larger processing facilities reduced the cost of production significantly. Then, the mining engineers of the day translated the reduced costs into lower cutoff grades, resulting in a steady decrease in the average grade of ore processed. At many operations, ore grades dropped from over 2% (typical underground mining grades) to 1.5% and in some cases below 1%. Gradually, as ore grades decreased and as wages and other costs inflated over time, production costs shifted back to the prior levels.

A review of the copper price curve (Figure 1) shows that the metal price experienced a sharp decrease from 1916 to 1921, but then a long period of general price increase occurred from the early 1920s to the mid-1970s. This is discussed further at the end of the flotation section.

Flotation

Bulk-oil flotation was patented by Mr. Francis Elmore in 1898 and was first applied commercially on a small scale at the Glasdir mine in Wales in 1899. It was described as a "dirty and nasty process" that cannot have presented much appeal to the owners and operators of the mining and smelting operations of the day. Mr. Elmore further developed this technology into a vacuum-oil flotation process in 1904, and several others developed and patented flotation processes between 1902 and 1907. The Minerals Separation Company was established in 1903 specifically to purchase and exploit the flotation patent that incorporated the use of air, water-soluble oil and dramatically reduced the amount of oil required (below 1%). The early days of flotation, between 1907 and 1923, are marked by extensive legal wrangling and litigation between many of the major copper producers of the day, Minerals Separation Company and others involved with the development and commercialization of flotation technology. This makes for highly entertaining night-time reading.[3, 4]

A number of copper producers tested and used flotation on a small scale. The Central Mill of Broken Hill in Australia is generally recognized as the first commercial application of the flotation process as we know if today, where the process was used to recover zinc. A large number of companies around the world tested the process between 1907 and 1915. In 1912, the Butte and Superior Copper Co. installed a 150-tpd flotation mill for zinc recovery and, because they ignored the Minerals Separation Patent, provoked the first lawsuit. In 1912, Inspiration Copper started testing the response of chalcocite ore to flotation and achieved 87% recovery from 2% copper ore into a concentrate containing 15% copper. The concept was to use flotation in place of traditional gravity concentration. Inspiration built a 50-tpd pilot plant in 1913 and a 600-tpd facility in 1914. Inspiration subsequently agreed to license the flotation process from Minerals Separation Company in 1915, and a 15,000-ton-per-day mill was commissioned in 1915. This plant achieved about 80% copper recovery, with approximately 72% obtained by flotation and 8% by gravity concentration. At the time, this was the second largest concentrator in the world, superceded only by Utah Copper's gravity-based concentrator (25,000 tpd).

Several copper companies tested and licensed the flotation process from Minerals Separation Company, including Anaconda, Miami and Utah Copper. Chino had a 12,000-ton-per-day concentrator that utilized flotation in operation in 1916. In the case of Utah Copper, flotation was first employed at Garfield in about 1918 at a modest scale, and then subsequent expansions and remodeling resulted in the eventual total conversion to flotation by about 1930. During this period, copper recovery increased from 64% prior to 1917, to over 80% by 1919, and then to 90% by 1930.

The importance of these initial large-scale commercial applications cannot be overstated. Firstly, flotation provided a step change in concentrator efficiency and performance by increasing the recovery from typical chalcopyrite and chalcocite ores from typically 64%–66% by gravity concentration to between 80%–90% by flotation. Secondly, the widespread commercialization of flotation occurred in parallel with the broad application of open pit bulk mining methods in the copper industry. These two technology developments were intimately linked. Referring to the commercialization of the flotation process, Hines[4] makes the statement "the total effect on the thinking of the mining industry was enormous even if the industry was slow in accepting all the new ideas." In this statement, he was apparently referring to the slow rate of adoption of flotation technology by the industry. But how slow really was this rate? The first large

commercial facility was commissioned in 1915. By 1928, there were large flotation mills at Utah, Chino, Miami, Inspiration, Braden, Chuquicamata, and many other copper mines. By 1930, over 75% of US copper production was generated by flotation. It is estimated that over 65% of copper production worldwide (which was dominated by the US and Chile) came from flotation plants at that time.

It is notable that the concentrator operating costs for flotation were about the same as those for the traditional gravity concentration process. However, on average, flotation technology increased copper recovery by about 15%, increasing the divisor by an equivalent amount for the purposes of production cost calculation. This was a huge step change in copper production technology.

Who benefited from the development of flotation? 1) The owners of Mineral Separation Company made a significant amount of money off licensing flotation technology until their patents expired in 1923. The company was liquidated at that time. 2) The first commercial users of the technology and the fast followers gained a significant and sustained production cost benefit. In addition, the reserves of many mines were increased as a result of lowering the cutoff grade of ore processed by up to 20%. This in turn allowed expansions to occur.

It is possible that the widespread commercial application of flotation contributed to the dramatic copper price decline experienced in 1930–1932. However, undoubtedly this dramatic price decline was heavily influenced by the Great Depression in the US, which greatly reduced copper demand for an extended period. It is interesting to note that this was immediately followed by an extended period of generally increasing price from 1933–1973, with some relatively minor dips. It is impossible to determine the exact impact of flotation on copper price. What is clear is that the most progressive, adaptive and innovative copper producers were able to achieve 10–15 years of competitive advantage from the rapid, broad and large-scale adoption of flotation at their operations. The slow adopters and "laggers" eventually followed or disappeared. By the 1970s, over 90% of primary copper (excluding scrap) was produced by flotation. Flotation has maintained its position as the dominant technology for processing of chalcopyrite and chalcocite ores from 1930 to the present day, although heap leaching is playing an increasing role in the processing of chalcocite ores.

Solvent Extraction and Electrowinning

The third and final example of technology development in the copper industry is the commercialization of solvent extraction (SX) and electrowinning (EW). Liquid ion exchange technology, or "SX" as it is now called, was first used commercially at the Ranchers' Bluebird mine, near Miami, Arizona, in 1968[(5)]. SX/EW technology replaced the pre-existing iron cementation process for the recovery of copper from low-grade copper solution obtained from leaching of oxide ore. Nine million pounds of copper were produced by the new process during its first full year of operation. In 1971, Bagdad installed an SX/EW facility to recover copper from stockpile leach solution. A tailings leach operation was commissioned at the Nchanga division of Zambia Consolidated Copper Mines (ZCCM) in 1974, utilizing SX/EW technology for copper recovery. Additional commercial-scale plants were then installed at Miami-BHP (1976), Miami-Inspiration (1979), Cananea (1980), Pinto Valley (1981), Tyrone (1984), Ray (1985), Gibraltar (1986), Morenci (1987), Sierrita (1987), Chuquicamata (1987), and Chino (1988). Widespread adoption in Chile did not occur until the mid-1990s with applications at Zaldivar, El Abra, Mantos Blancos, Quebrada Blanca and many others.

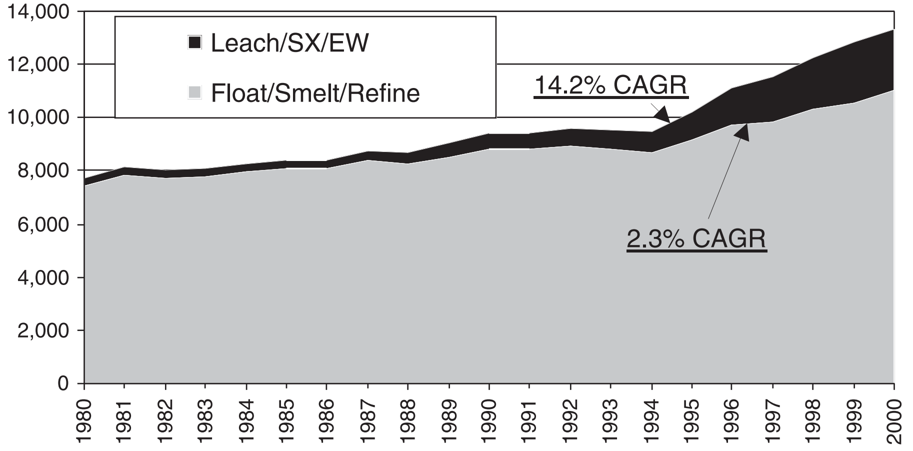

FIGURE 2 Annual copper production by leaching/SX/EW and flotation/smelting/refining from 1980 to 2000

The major advantages for most of these operations were 1) the replacement of costly and labor-intensive iron cementation process that generated a precipitate for further processing by smelting, and 2) the ability to expand heap and stockpile leaching operations significantly by the use of larger volumes of leach solution as a result of the ability to efficiently process large volumes of low-grade copper solution by SX. This provided a low-cost supplement of copper production to the core flotation concentrator facilities in many cases. The Miami-Inspiration concentrator shut down in 1986 and the Tyrone concentrator shut down in 1992, resulting in both of these operations evolving into an all-SX/EW production base. These events were major milestones that allowed copper companies to consider stand-alone leaching and SX/EW operations to be developed, providing a lower cost process for extracting copper from chalcocite and oxide ores. While many factors affect the production cost calculation and comparison between leaching/SX/EW and flotation/smelting/refining processes for chalcocite ores, it is apparent that the former process route initially presented a 15%–25% cost advantage. Once again, this was not intuitively obvious at the time and it took a number of years for this concept to germinate into a commercially applicable technology. In the 1990s many stand-alone chalcocite and oxide ore leaching/SX/EW operations were developed and successfully placed into production.

How did the advent of SX/EW technology affect copper market fundamentals? Figure 2 shows the production of copper by leaching/SX/EW and flotation/smelting/refining from 1980 to 2000. SX/EW accounted for about 3% of total primary copper production in 1980, increasing to about 8% by 1994, and to just over 18% by 2000. Similarly to flotation, it is difficult if not impossible to directly link the commercialization of SX/EW technology with a period of copper price decrease. The most likely period of impact is the period 1994–2000 when the proportion of copper produced by SX/EW more than doubled. It can be seen that the copper price decreased significantly during the period 1995–2001; however, other market forces played a significant role during that period and it is unlikely that technology played a dominant role. The next decade of the copper cycle will reveal more on the impact of SX/EW technology.

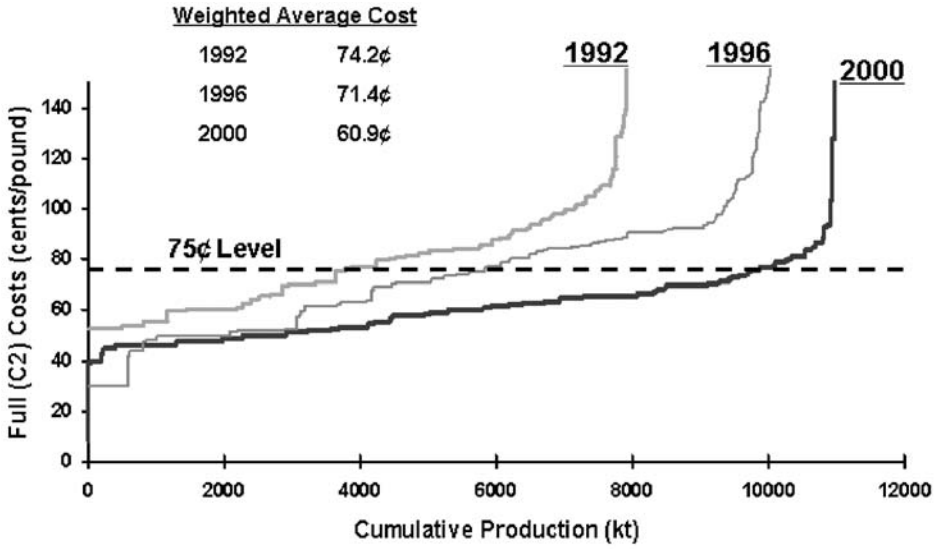

FIGURE 3 Estimated copper production cost curves for 1992, 1996 and 2000

Based on remaining copper reserves by ore type, it is projected that leaching/SX/EW will account for about 21% of total production by 2010. This assumes that there is no technology breakthrough for the atmospheric leaching of low-grade chalcopyrite ores and excludes any impact of leaching processes to treat concentrates as an alternative to smelting and refining.

Other Technology Developments

There have been many other technology developments that are not discussed here. Some of the other significant developments include the reverberatory furnace, tube and ball milling, flash smelting, autogenous and semiautogenous milling, in-pit crushing and conveying, computer control of processing and mining operations, and use of increasingly large-scale mining equipment.[7] There have been many other incremental improvements, changes and innovations that have helped shape the copper industry over time. Many of these have provided sustainable competitive advantage to the users of the technology.

Impact of Technology Developments on Production Costs

Figure 3 shows the full production cost curve for primary copper production (excluding scrap) for 1992, 1996 and 2000. The full cost includes cash production cost plus depreciation and amortization. The graph shows that as production volume increased over time from 1992 to 2000, the cost curve flattened and the average production cost decreased from \$0.74/lb to \$0.61/lb. A significant portion of this decrease was due to low cost, new production coming on line, but a portion was due to technology developments. However, an important point to make from this graph is that relatively modest decreases

in production cost can have a huge impact on competitiveness between mines and companies. For example, a 15% decrease in production cost, say from $0.70/lb to $0.60/lb, moves a producer from the bottom of the fourth quartile to the top of the second quartile on the cost curve. The producers who adopted open pit mining, flotation and SX/EW technology reaped the benefit of similar order-of-magnitude changes in their cost profile and changed the fate of their companies forever. Sustainable competitive advantage indeed.

SUMMARY AND CONCLUSIONS

Competitive technology developments have reduced the production costs for all commodity metals over time, either through significant step changes, such as those discussed in detail above, or by incremental change. In the case of copper, there is some evidence that major step change technology developments have contributed to an increased availability of commodity metals, resulting in downward pressure on metal prices. However, other market forces including reserve and resource availability and quality, mine investment decisions, commodity metal demand, economic conditions and trends, and other factors have dominating effects on the long-term commodity metal markets.

In the case of the three examples used in the copper industry case study, much of the industry was slow to adopt new technology, even after its effective use had been clearly (and publicly) demonstrated. Step change technology developments allow the innovative and progressive producers to achieve a sustained advantage over a significant proportion of their competitors for periods of 10–15 years, and in some cases even longer.

While the use of patenting and the confidential retention of proprietary know-how, trade secrets and expertise can be effective in providing short- to medium-term competitive advantage, it is probably other factors such as the speed of adoption, the effectiveness of implementation, and the scale of application of new technology that provides the biggest competitive advantage. The ability to apply technology more widely throughout an organization than a competitor is an advantage that in many cases cannot be duplicated due to geographical and geologic (resource) factors.

In conclusion, this author believes that a strategically-driven and sharply focused technology development effort, along with an effective implementation program that actively manages risk, is a requirement for every thriving, sustainable mining company.

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Alternatives to SAG Milling

or

SAG Milling! Have We Evolved? Are We Stuck?

State of the SAG

James L. Vanderbeek*

INTRODUCTION

Semiautogenous (SAG) grinding technology first started to be seriously considered for comminution circuit design in the mid-1960s as an alternative to the three-stage crushing circuits and rod-ball mill circuits in vogue at the time. Since this time the application of SAG mill technology has become widespread with over 250 mills larger than 20 feet in diameter sold (Jones 2002). The vast majority of concentrators constructed over the past quarter century have utilized SAG mill technology, and a SAG-based comminution-based circuit is generally the first choice considered for new projects.

Since the first generation of SAG milling technology was applied, many lessons have been learned, and new supporting technologies have emerged which make the design, installation and operation of SAG mill–based grinding circuits more robust and efficient. This paper will discuss the current status of SAG and associated technologies.

MILL MECHANICAL DESIGN ISSUES

Table 1 summarizes the manner in which SAG design capability has evolved over the past 30 years. Increases in mill diameter came slowly as the industry took a wait-and-see attitude as the technology of larger mill diameters was advanced. The first 32-foot-diameter mill was ordered in 1969. It was not until 1979 that the technology jumped to the 34-foot-diameter mill and 1988 for the first 36-foot-diameter mill. The first 38- and 40-foot-diameter mills were both ordered in 1996. At least five 38-foot-diameter and two 40-foot-diameter mills will be in operation by mid-2004.

Advances in structural analytical techniques and increased computational power, coupled with field measurements of large operating mills, have increased the confidence of the mill suppliers in their designs and the operating companies in the viability of larger diameter mills. No failures of a 36-foot-diameter mill or larger have been

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TABLE 1 Evolution of SAG mill diameter and drive power

Mill Diameter			Installed
Feet	Meters	Year of Initial Order	Drive Power Range (MW)
28	8.54	1970	4.5–5.6
32	9.76	1969	7.8–8.2
34	10.37	1979	9.3–11.0
36	10.98	1987	11.1–13.4
38	11.59	1996	18.0–20.1
40	12.2	1996	19.4–21.0

experienced. This is not to imply that the design of a large diameter SAG mill has become a trivial activity.

The engineering companies, the mill vendors and the gearless drive vendors have come to recognize that the mill, the gearless drive and the mill foundation form a system. Procedures have been established to analyze the interactions between the members of the system to make sure that no natural frequencies are excited during normal mill operation.

The installation of a locked charge protection system is critical for large diameter SAG and ball mills. This capability is inherent with the gearless drives.

The larger diameter SAG mills have provided significant improvements in capacity compared to smaller diameter mills. However, the larger mills also require the production of larger cast components. There are a very limited number of organizations capable of producing these castings worldwide.

The consensus of the mill vendors is that the current trunnion supported bearing SAG designs can be extrapolated to the 42-foot or 44-foot-diameter sizes without significant problems. Diameters larger than this size will require a redesign of the bearing system.

OPERATIONAL ISSUES

Operating Time

SAG-based grinding circuits are achieving grinding circuit operating times in excess of 94%. Ten or fifteen years ago plants were designed to operate at comfortable 90% operating times, and achieving 92% operating time in practice was considered a good effort. These levels are rarely tolerated today.

Two factors must come together to achieve a high grinding circuit operating time. First, efficient mill liner replacement procedures are required since replacing mill liners is always the single largest source of grinding circuit downtime. It is becoming recognized (Russell 2001) that implementing good liner replacement practices requires the concurrent efforts of the owner's operations and maintenance staff, the mill vendor, the liner vendor and the engineer. Basic requirements for an efficient liner removal system include

- Convenient liner staging areas for new and used liner storage with direct access to the mills

- An efficient mill feed chute removal procedure which may involve a motorized chute or a chute transport device
- A robust and reliable liner handler that will efficiently pick up and place new liners in position and efficiently pick up old liners from the mill charge for removal
- A recoilless hydraulic powered bolt removal tool(s).

Liner design also plays an important role in achieving effective SAG performance and operating time. A significant development of the past 5 years is the now widespread use of discrete element modeling (DEM) techniques (Rajamani and Mishra 1996) to predict particle trajectories as a function of liner design within the mill with many operations trending towards shell liner face angles in the 20–30 degree range.

The performance of grinding circuit ancillary equipment (screens, trommels, pumps, cyclone feed lines) also plays an important role in achieving satisfactory grinding circuit operating time. Increased stress has been placed on this ancillary equipment as mills have become larger. High-quality equipment is required which can operate untouched throughout the maintenance cycle. This may be in conflict with the standard competitive bidding process unless life-cycle performance is specified and analyzed.

Process Control

Current instrumentation capabilities are beginning to catch up with SAG circuit process control activities. The determination of size distributions of coarse conveyed material via video monitoring is now relatively common. An effective installation should include monitoring of primary crusher feed, primary crusher discharge and SAG fresh feed. Acoustic systems are being applied to the SAG mills to infer charge trajectory, ball charge level, total charge level and measures of ball-to-rock interactions. Contact (sensor[s] mounted on the mill measuring vibration spectrum) and noncontact (array of microphones arranged around the mill) systems are in various stages of development. At the minimum, a Hardinge Electric Ear should be installed.

Effective mill operation requires the use of an expert or an adaptive control system. The system should be programmed such that control disturbances to the grinding circuit are minimized. The more effective systems allow mill levels to “float” within reason as ore feed characteristics change rather than controlling to rigid power or bearing pressure targets.

PEBBLE CRUSHING

The SAG milling and pebble crushing processes are intertwined. Pebble crushing circuits were added to several of the early SAG operations to address the characteristic of SAG mills that they do not efficiently process “critical” material in the −75 mm +12 mm size fractions. The potential effect of the addition of pebble crushing to a SAG circuit is illustrated in Tables 2 and 3. Table 2 contains a summary of SAG-ball mill and SABC circuit projections for a current project. A 13.4% reduction in overall grinding circuit specific energy was projected with the addition of pebble crushing. A 35% reduction SAG power was noted for this relatively hard ore. Table 3 illustrates the magnitude of pebble crushing circuit capital costs relative to the overall grinding circuit for a 100,000-tpd concentrator. The extra capital required to install the pebble crushing circuit was 10.8% of the overall grinding circuit (SAG-ball mill only). However, addition of the pebble crushing

TABLE 2 SAG-Ball mill and SABC circuit characteristics

	SAG kWh/t	SABC kWh/t	% Difference
SAG	10.4	7.7	–35.1
Ball Mill	8.2	8.4	
Pebble Crushing	0.0	0.3	
Total	18.6	16.4	–13.4

TABLE 3 Grinding and pebble crushing circuit capital costs (100,000-tpd concentrator)

Area	Capital Cost ($000)
Grinding	249,940
Pebble Crushing	27,042

circuit allowed the desired project throughput goal to be achieved with two grinding lines rather than three grinding lines.

Key features of effective pebble crushing circuits are

- A significant proportion of the pebble crusher product must pass the SAG screen. If this is not the case then the benefits of pebble crushing will not be obtained.
- An effective tramp steel protection system must be installed with multiple magnets.
- If material captured by the magnets is returned to the milling circuit, a method to purge steel from the mill must be available.
- Sufficient SAG screen/trommel capacity must be installed to prevent wet, fine material from entering the crushing plant.
- Surge or storage capacity of pebbles before the crushers must be installed in the form of a bin or a stockpile. The natural variation in pebble production from the SAG mills must be decoupled from pebble crusher feed.

ORE CHARACTERIZATION

The key to properly designing a grinding circuit is to understand the variability in ore hardness that the circuit must handle. Historically, SAG mills were sized based upon the results of 6 × 2 foot pilot mill tests on material collected from adits or large diameter drill core. Based upon these results and the experience of the individuals performing the analysis, accurate estimates could be produced of SAG specific energy requirements. The procurement of the samples for testing and the performance of the pilot-scale SAG testing is an expensive proposition. The problem with the pilot-scale testing approach was that it was never clear or certain how closely the material tested would correlate with the material that would actually be mined and processed through the plant. In other words, how representative was the sample tested in the pilot plant?

The single most significant advancement in SAG mill technology in the past 5 years has not been the evolution of the mill sizing to the 40-foot-diameter level but has been the commercialization of the Starkey SPI test by Minnovex (Dobby, Bennett and Kosick

2001). This procedure uses a 2-kg sample, readily obtainable from drill core, to characterize the SAG and ball mill performance via the SPI (SAG Performance Index) test and via Bond testing. The key is that a large number of samples can be economically tested to determine a profile of hardness variation across the entire ore body or portions of it. Armed with this knowledge SAG and ball mill sizing can be determined such that production rates and flotation feed sizing can be produced over the period of interest, be it the first 5 years of mine operation or the life of the mine. Characteristics of ore bodies, such as ore hardness, tend to change with time. Unfortunately, the characteristics and capacity of a grinding circuit are relatively fixed upon installation. The ability to economically pre-determine the variation in ore hardness across and ore body removes much of the process risk from SAG circuit design and eliminates the requirement for large-scale pilot testing to determine SAG milling characteristics.

SUMMARY

SAG milling technology has evolved over the past 35 years to where it is a robust and mature technology. Mill mechanical design techniques are well understood and validated. SAG circuit operating times can exceed 94% due to increased emphasis on mill liner design, efficient mill liner replacement and the installation of high-quality ancillary equipment such as screens and pumps. Instrumentation enhancements such as SAG acoustic sensors capable of inferring charge volume and ball charge will aid process control techniques. The current ability to economically characterize hardness variations across an ore body takes much of the process risk out of grinding circuit design.

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Fully Autogenous Grinding from Primary Crushing to 20 Microns

R.E. McIvor* and T.P. Weldum†

INTRODUCTION

Cleveland-Cliffs' operations in Michigan have been utilizing fully autogenous grinding for over four decades. This is but one of the key characteristics of the iron ore processing method that was developed for the extremely fine grained, low grade deposits of the region. Liberation size of the hematite and magnetite ranges from about 30 to less than 1 micron. Typical grinding fineness target to achieve silica grade in the concentrate is 80 to 90% passing 25 microns, or a P80 of approximately 20 microns. After primary grinding, the magnetite ore is first upgraded by rougher magnetic separation. It is then ground to final product size, sent through thickener-sizers utilizing selective flocculation, upgraded again by finisher magnetic separation, and then brought to final silica grade by reverse amine flotation. Hematite ore follows essentially the same route, less the magnetic separation stages. Concentrate is filtered and pelletized, along with controlled additions of fluxstone, to ready it for shipping. Iron ore pellets on the water of the Great Lakes have a value of approximately 1.5 cents per pound.

GRINDING PROCESS DESCRIPTION

Details of the Empire magnetite grinding process flowsheet have been presented by Greenwood and Rajala (1992), and more recently by Rose et al. (2002). The Tilden comminution process for either magnetite or hematite is essentially identical, with the exception of some variations in the excess pebble treatment methods (McIvor and

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Greenwood 1996) and of bypassing the rougher magnetic cobbers on hematite. The Tilden grinding circuit is shown in Figure 1, and, except as described otherwise herein, depicts the process at both operations.

Grinding is preceded by mining and primary crushing. The crusher closed side setting is 9 inches (225 mm) on hematite, slightly smaller on magnetite. The opening is maintained just tightly enough to prevent numerous chute hang-ups between the crusher and the primary mills. Chunks are needed for good primary mill throughput; the more and the larger, the better for tonnage.

Empire was built in four stages from 1961 to 1975. Tilden was built in two stages, in 1974 and 1979. The oldest primary mills are 24 feet (7.3 m) in diameter, and the newest are 32 feet (9.8 m). A few of the earliest pebble mills at Empire are 12.5 feet (3.8 m) in diameter, all the rest being 15.5 feet (4.7 m). The ratio of primary autogenous to secondary pebble mill installed power is approximately 1.7 to 1 at Empire and 1 to 1 at Tilden. Pebbles have always been generated in the primary mills for use as media in the pebble mills. Tilden provided for crushing of excess pebbles from inception of both stages. The first pebble crushing was added to Empire section IV in 1985. Pebble crushing has since been retrofitted into Empire III and part of Empire II. Ball milling of a portion of the crushed excess pebbles was implemented at Tilden in 1995, the sole exception to "medialess" grinding of the ore at either operation. (Ball mills are used to grind fluxstone.) Finally, high-pressure rolls grinding of the crushed, excess pebbles on Empire section IV was installed in 1996.

Crushing of excess pebbles adds approximately 15% to primary milling throughput rate on softer ores, and 25% on hard ores. High-pressure grinding on Empire IV boosts throughput there by approximately another 15%. Ball mill grinding of crushed pebbles adds approximately 10% to primary milling throughput at Tilden.

SPECIAL FEATURES

While nothing about them (with the exception of some excess pebble treatments) is completely unique, the following "special features" of these circuits are noted for comparison with the widely used SAG–ball milling circuit, with or without the aid of pebble (or "critical size") crushing internal to each circuit.

1. Total cost of grinding media is zero. This compares to what might very well be the greatest single consumable cost for a metal producing company.
2. Primary milling impact breakage is well augmented by external crushing, etc. The total benefit of crushing and high-pressure grinding of excess pebbles approaches (within 10%–20%) that of complete removal of pebbles.
3. Secondary pebble milling has been subject to extensive optimization (McIvor et al. 2000) and circuit efficiency is excellent. Pebble milling circuit operating work indices of 10 kwh/mt (no "correction factors") were measured processing hematite ore (although higher on upgraded magnetite concentrate from rougher magnetic separation) with a laboratory Bond work index of 14 kwh/mt. This may be attributed to a number of factors, but two are outstanding. There is an excellent water balance at the cyclones (McIvor and Weldum 2003), but more relevant here is the fully graded make-up charge (from $-2\frac{1}{2} + \frac{1}{2}$ in., or $-63 + 13$ mm) that pebble usage for media provides (Loveday 2001).

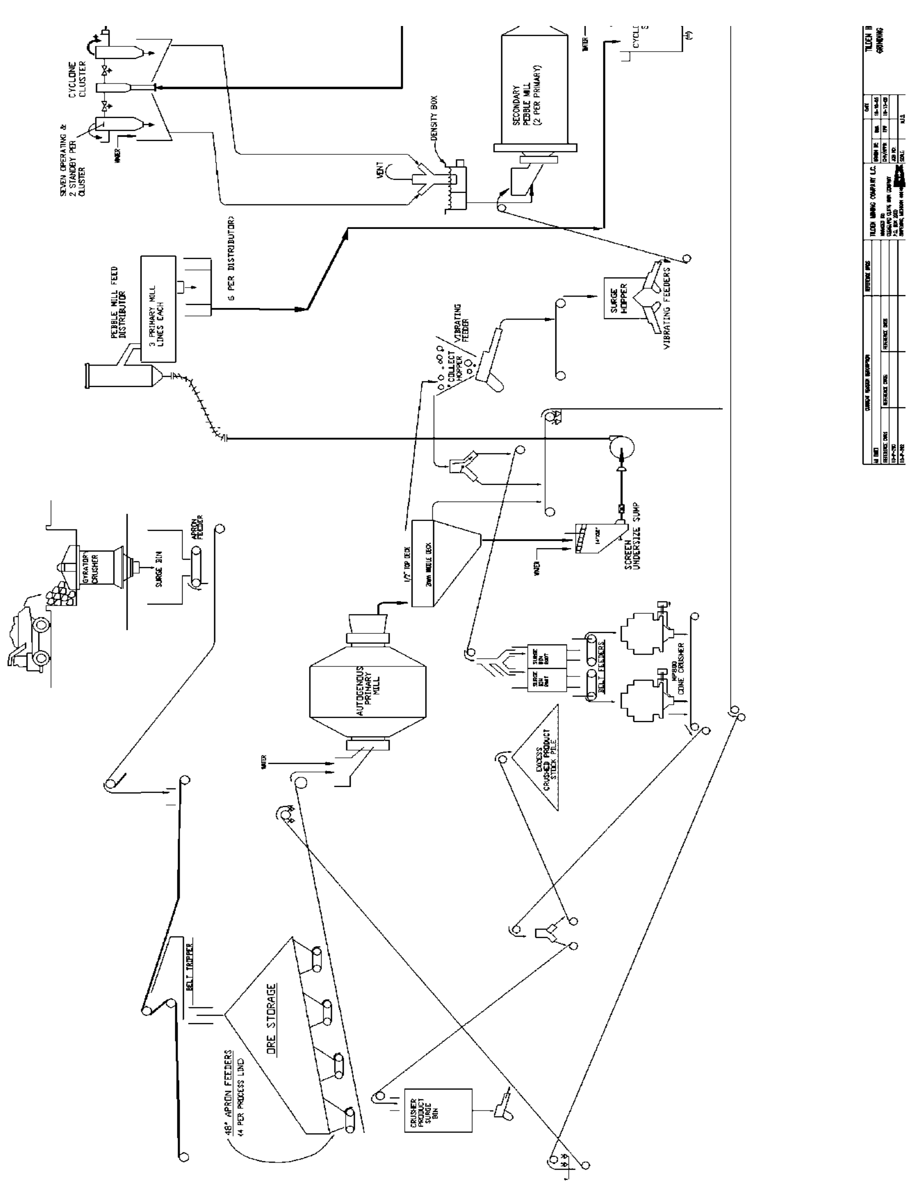
SEVEN OPERATING & 2 STANDBY PER CLUSTER
CYCLONE CLUSTER
DENSITY BOX
VENT
SECONDARY PEBBLE MILL (2 PER PRIMARY)
PEBBLE MILL FEED DISTRIBUTOR
3 PRIMARY MILL LINES EACH
6 PER DISTRIBUTOR
COLLECT HOPPER
VIBRATING FEEDER
SURGE HOPPER
VIBRATING FEEDERS
GYRATORY CRUSHER
SURGE BIN
APRON FEEDER
AUTOGENOUS PRIMARY MILL
SCREEN UNDERSIZE SUMP
BELT FEEDERS
MP800 CONE CRUSHER
EXCESS CRUSHED PRODUCT STOCK PILE
BELT TRIPPER
ORE STORAGE
48" APRON FEEDERS
(4 PER PROCESS LINE)
CRUSHER PRODUCT SURGE BIN
WATER

FIGURE 1

4. Pebble removal from primary grinding contributes directly to additional primary grinding tonnage. And media (pebble) wear contributes to additional secondary milling tonnage. Nor are the figures trivial, in this case averaging slightly over 5 percent.
5. Primary mill liners are extremely hard and long wearing, the danger of ball impact being non-existent.
6. Pebble crushers are not subject to potential damage from primary grinding balls.
7. With the flexibility to recycle excess pebbles back to the primary mills when grinding is pebble mill limited, the control system can quickly adjust to obtain higher power draw and a finer grind from primary milling.
8. The less primary crushing (meaning also lower primary crushing cost), the better. While coarser feed has long been experienced to be positive for primary autogenous or semiautogenous milling, some modern-day practitioners have gone to such extremely high ball charges that this effect is reversed, i.e., the finer the crushing ahead of the mill, the higher the tonnage.

There are also real and potential disadvantages to this circuit for new operations. Piloting work may be substantial to absolutely ensure an adequate pebble supply, since the lack of same would be disastrous. Capital costs for grinding circuit equipment would be higher. The production of extreme fines from pebble wear may be less than optimal for downstream processing (McIvor and Finch 1991). And the effect of using autogenous versus steel or iron media on slurry chemical properties should not be neglected (Martin et al. 1991).

CONCLUSION

Fully autogenous grinding, from the primary crusher product to a final product P80 of 20 microns, has proven to be extremely cost effective for Cleveland-Cliffs' Michigan operations. The comparative high operating cost of the media needed for SAG–ball mill grinding, in all likelihood, would have forced closure of these mines years ago.

From early extensive test work, there was little doubt that autogenous primary grinding of these ores would provide more than ample pebbles for secondary grinding. The enormous long-term cost implications suggest that this is an approach that should be fully investigated at the design stage of each new operation.

ACKNOWLEDGMENT

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HPGR—The Australian Experience

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INTRODUCTION

This paper traces the application of High Pressure Grinding Rolls (HPGR) at industrial and pilot scale in Australia. The Argyle Diamond Mine installed the first of two smooth segmented HPGRs during 1990 in an open-circuit secondary-tertiary crushing application to increase throughput. In 2002 a third HPGR was added to improve liberation and so increase the recovery of smaller diamonds. The latest improvements in wear technology (tyre with tungsten carbide studs) were incorporated in the design of this machine.

Extensive HPGR pilot-plant trials were undertaken during the 1990s at both the Kalgoorlie Consolidate Gold Mine and the Boddington Gold Mine. The purpose of these trials was to evaluate HPGR as a method to increase throughput, as an alternative to SAG milling, and also to ascertain if downstream benefits existed.

One of the challenges for HPGR circuit designers is to translate what occurs at small laboratory and pilot scale into what is likely to happen in a full-scale circuit. Scale-up from pilot machine results is normally recommended by manufacturers. However, such tests need relatively large quantities of material, particularly if meaningful data on wear are to be obtained. Laboratory tests are preferable, as they need relatively small quantities of ore, but may be questioned in terms of how they relate to full-scale operation. Modelling and simulation have played a particularly important role in this respect in Australia. Models are available which have proven to be very accurate at being able to scale throughput and specific energy response from laboratory to industrial machines. More recently, work in Australia has also been done in developing a model which has the potential to scale laboratory wear data as well.

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COMMERCIAL APPLICATION OF HPGR ARGYLE DIAMOND MINE—BACKGROUND

To date Argyle Diamond Mine is the only mine within Australia to utilise HPRC technology and now has three roller presses in operation. Argyle introduced HPGR technology in 1990 in an effort to counter the problem of increased ore hardness and also to increase throughput capacity (Hutton 1994). Prior to this, the ore supply was mainly weathered lamproite (Bond Work Index 10 kWh/t and Abrasion Index 0.22). As mining in the open pit progressed at depth, the more competent unweathered lamproite became the predominant feed source (Bond Work Index 18 kWh/t and Abrasion Index 0.60). The crushing circuit was limited by both its tertiary and coarse tailing re-crushing capacity with the harder ore. A study was carried out to see if the existing Allis Chalmers tertiary crushers could be replaced or supplemented to remove this bottleneck. Several variations of the cone crusher were considered and none appeared to offer substantial benefits. At that time the HPGR type of crusher seemed to offer a workable solution. However, it was only when the effect of placing the HPGR upstream of the tertiary crushers, and directly after the secondary crushers, was studied that the true benefit was demonstrated. This showed the potential to produce in excess of 30% minus 1 mm in the HPGR crushed product. This would remove the bottlenecks in the downstream crushing circuits and lift treatment capacity from 4.5 Mtpa to 6.4 Mtpa.

Three German crusher manufacturers held licences from the patent holder to build HPGRs. These were Krupp-Polysius, KHD Humboldt-Wedag (KHD) and Koeppern. The decision was made to purchase a single 2.2-metre-diameter by 1.0-metre-long unit with smooth rolls from Krupp-Polysius capable of treating 600 tph. KHD could only offer three 200-tph units for the duty and Koeppern had not sold a production unit. The first roller press purchased had twin 1,200-kW motors with fixed speed drives. The second HPGR installed in 1994 had twin 1,800-kW motors with variable speed drives. This machine was installed to further increase throughput capacity and so maintain diamond production. The diamond content in the feed was predicted to decrease with extended mine life.

Operation of the Smooth Roll HPGR

The HPGR crushing duty is arduous, treating a secondary crushed product with an 80% passing size of nominally 75 mm. Lumps of up to 250 mm enter the feed on occasion, due to the fact that the secondary crusher operates in open circuit.

The first few years of operation were problematical with the main issue revolving around wear on the roll tyres and check plates. The first set of tyres of solid Ni-hard failed after 6 hours in service. The second set wore out in 10 days and the time required to change out the solid tyres was around 20 days. As a result of these events, it was decided to move towards a bolt on segmented design.

Over the years various roll surface wear materials have been tested ranging from hard facing compounds to Ni-hard alloys. The process has been optimised to the point where the Ni-hard segments last around 6 weeks, treat around 475,000 tonnes and wears down the surface of the rolls by some 150 mm. The time required for a change-out has been reduced to some 30 hours and the utilisation has steadily increased from 42% to 76%.

Another issue encountered was excessive wear on the cheek plates. This was serious enough that these were replaced with a customised bypass rock box. This caused a loss in comminution efficiency due to “edge” bypass and also led to an acceleration of wear

in the center zone of the roll surface. An unacceptable "bath tub" profile resulted requiring the roll surface to be regularly ground "on-line" to provide an acceptable wear profile. The additional utilisation more than compensated for the high cost associated with this procedure.

Application of HPGR with Studded Rolls

The process circuit at Argyle is essentially a large-scale crushing and screening plant preparing ore for subsequent diamond recovery. Comminution is undertaken down to a quaternary crushing level via conventional cone and HPGR crushers. Investigations carried out in the late 1990s indicated that additional diamond liberation and recovery could be achieved by decreasing the crushed size of the recycled coarse tailings (Maxton, Morley, and Bearman 2003). However this would substantially increase the recycle load in the tertiary/re-crushing circuit. A study at that time showed that the addition of a HPGR to replace two cone crushers would have the benefit of maintaining the same plant throughput capacity (i.e., no increase in recycle load). Furthermore advances had been made in the area of HPGR "studded" roll surface technology (to improve wear characteristics) to the extent that two mines in North America had installed it on their HPGR machines. In addition to improved surface wear there appeared to be throughput benefits with a "studded" roll.

Pilot-plant testwork. To quantify the benefits a detailed pilot plant, testwork was undertaken at the CSIRO Division of Minerals in Perth. The testwork program confirmed the formation of a competent autogenous layer between studs (a condition necessary to improve wear) using the primary unweathered lamproite. It was found that the throughput appeared to be a strong function of truncate feed bottom size—which is the main influence on bulk density. Also for a given feed bulk density the moisture content influenced throughput negatively. This is more pronounced at higher roller speed. An increase in specific throughput of up to 40% was predicted from the testwork using a studded rather than a smooth surface on the HPGR.

Design and operation of circuit. The new circuit was commissioned in 2002 and has a capacity in excess of 750tph at the maximum roller speed. There is VSD control to facilitate 300 tph at the minimum roller speed. The normal operating pressing force is around 3.2N/mm^2 with capacity to increase this to a maximum of 4.5N/mm^2. Screens ahead of the HPGR ensure a feed top–size restriction of 25 mm and the product particle size is 80% passing 8 mm, and more critically 36% passing 1.18 mm.

An essential part of the circuit is the removal of tramp metal to protect the HPGR. The system consists of a self-cleaning magnet to remove the majority of magnetic tramp on the conveyor feeding the main HPGR feed bin. A high-sensitivity metal detector is installed directly after the tramp metal magnet. Upon detection and after an appropriate time delay the shuttle on the conveyor discharge diverts around 10 tonnes of feed into the tertiary cone crusher bins. In addition another high-sensitivity metal detector is installed on the feeder from the main HPGR bin to the HPGR pre-bin to protect tramp entering the circuit downstream of the main storage bin. Upon detection, and after a small time increment, an air-actuated system allows bypass of the feed to HPGR.

Operating experience over the 12 months of operation revealed a serious issue that contributed to much lower machine utilisation than expected. The shoulder edges on the HPGR do not have autogenous protection and wore down to the extent that welded strips of hard facing was required to protect the edge. The hard facing buildup was carried out

every 320 hours, resulting in approximately 60 hours downtime. A new design modification will address the need to weld by changing the edge design to accommodate bolt-on "sacrificial" edge segments. A preliminary trial of the concept, where relatively small edge segments were welded in place, was evaluated on the first tyre set, and the result of this trial was encouraging.

As the studs on the surface of the rolls wear down, shims are removed to bring the distance between the fixed and floating rollers to a predetermined minimum when on the mechanical stops (i.e., zero gap). This maintains the zero gap at a minimum of 15 mm to avoid diamond breakage.

The cheek plate tips are made with a 10-mm-thick tungsten carbide layer and last approximately 1,000 hours. The performance of the cheek plates in general is acceptable. Inexpensive cheek plate insert liners sit above the expensive tips and are replaced every 2 to 3 weeks.

Operationally the new circuit modifications have met design expectations. The HPGR was commissioned during February 2002 and the first set of tyres lasted 3,764 hours and crushed 2,035,555 tonnes of ore. Downtime due to equipment failure was negligible.

Cone crushing versus HPGR. An evaluation of the comminution performance of the HPGR compared to the performance of conventional cone crushing was made during one shutdown period for HPGR roll edge welding. For this evaluation two standby cone crushers were used. The conclusion drawn from interpreting the data is revealing but not considered to be definitive. As expected the cone crushers utilised low energy of around 0.5 kWh/t and generated minus 2.3 mm material in the region of 8%–10%, whereas the HPGR operates at energy levels up to three times higher and generated 32%–48% of minus 2.3 mm material.

PILOT PLANT TRIALS IN AUSTRALIA

Kalgoorlie Consolidated Gold Mine Trial

Background. In 1993 the Kalgoorlie Consolidated Gold Mine (KCGM) examined the option of installing HPGR technology as a way to increase treatment capacity from the already 4.8 Mtpa to 7.5 Mtpa (Watson and Brooks 1994). The initial phase of the study consisted of laboratory-scale testwork in Germany followed by an engineering study using parameters derived from the laboratory testwork. The study showed possible operating and capital cost savings compared to alternative processing routes by including an HPGR unit in the existing tertiary crushing circuit to reduce ball mill feed size. The study also highlighted a number of process and technical concerns that required resolution prior to commitment to the application of HPGR technology. To provide the necessary information a HPGR pilot-plant trial was undertaken during the latter part of 1993. An evaluation of the results from the pilot plant showed that there was no capital and/or operating benefit in considering HPGR technology. Two HPGR units with "smooth" rolls and an additional ball mill were required for the expansion. Smooth rolls were selected due the problems experienced during the pilot-plant trial with stud breakage on the studded rolls. Furthermore no discernible downstream benefits were found in flotation and cyanide leaching. Consequently it was considered that HPGR technology was not the best option for the expansion.

Pilot-plant trial. The objectives of the pilot plant were to demonstrate the technical feasibility of the HPGR process on a larger and continuous scale. It was also important to

confirm the process flowsheet developed in the initial study phase and generate metallurgical and engineering data for the design. There was a need to refine operating cost estimates especially for component wear on the HPGR and assess any potential downstream benefits in milling, flotation and cyanide leaching.

Both KHD and Krupp-Polysius were approached to supply a pilot-plant unit for the trial. Due to time constraints the only pilot machine available was an RPV 90/25 model supplied by KHD. This was a converted briquetting machine with upgraded drives and gearboxes. The pilot unit was supplied with both smooth and studded segmented liners.

Details of the unit are

Model Number	RPV 90/25
Roll Diameter	900 mm
Roll Width	250 mm
Motor Power	2 × 90 kW
Roll Speed	0.94 and 0.87 m/s (pulley drives)

HPGR pilot-plant trial. The gold ores at KCGM are mined from carbonate-altered basalt and dolorite lodes. The Bond rod and ball mill work indices vary respectively from 13 to 16.3 kWh/t and 14.1 to 16.5 kWh/t, while the Bond abrasion index (Ai) varies between 0.08 to 0.34. Parcels of ore for the HPGR pilot-plant program were prepared at one of the existing crushing facilities at KCGM. The ores were crushed to nominally 100% passing 50 mm using a jaw and cone crusher in open circuit. The crushed ore was stockpiled ahead of the pilot plant and reclaimed by front-end loader. The feed rate to the HPGR was controlled by means of a load cell to maintain a constant level in the feed box and ensure the HPGR was choke fed. Both a permanent magnet and metal detector were installed ahead of the HPGR for tramp metal protection. A weightometer located on the HPGR feed conveyor measured the feed rate The crushed product discharged into a bifurcated chute arrangement with internal cutters to separated edge and center discharge material. The cutters were manually adjusted to remove anywhere from 0% to 50% of the product. The products (edge and center) were stockpiled separately.

Unfortunately the planned pilot-plant testwork program had to be modified due to limited plant availability as a result of wear problems encountered on the HPGR. The most significant of these was excessive wear on the check plates, the first set of plates only lasting half a day. After testing numerous wear materials over many weeks some success was obtained using a two-piece plate arrangement with 19-mm tungsten carbide squares. Dust management was also an issue and additional water sprays were installed around the circuit.

The following observations were made from the pilot trial:

- Increasing the amount of fines in the feed increased the amount of flake in the HPGR product and the crushed product size was finer.
- Increasing the moisture resulted in a slight decrease in throughput and an increase in flake production. Wear also appeared to increase the wetter the ore.
- The specific power consumption increased with smooth liners resulting in an increased fines generation in the minus 106-micron fraction. The operating gap for the smooth liner configuration was less than the studded liners and consequently the throughput was 60% less than for the studded configuration.

TABLE 1

	HPGR Ore	Tertiary Crushed Ore
Feed rate to the ball mill (tph)	14.7 (3.5)	12 (1.2)
Feed size (F80 mm)	4,340 (950)	5,930 (460)
Product size (P80 mm)	101 (24)	117 (28)
Operating work index (kWh/t)	12.0 (1.1)	14.4 (0.5)

Figures in brackets—standard deviation.

A 200-tonne sample of HPGR crushed product, including edge material, was processed through a pilot-scale vibrating screening plant with deck apertures of 12.0 mm and 6.75 mm. No de-agglomeration stages were undertaken prior to screening. Screening efficiencies of greater than 90% were achievable.

Ball mill trials on HPGR product. Two ball-milling trials using a 2.4-m-diameter mill were conducted on both tertiary crushed ore and HPGR product to assess if there were any differences in grindability. Mill surveys of 30-minute duration were performed during the trials. Slurry samples from key locations around the circuit and mill feed were taken at 5-minute intervals. A summary of the data is shown in Table 1.

The Boddington Gold Mine Trial

Background. Gold production at the Boddington Gold Mine (BGM) in Western Australia commenced in late 1987 and oxide reserves provided a mine life of 14 years. In the early 1990s work commenced on evaluating the viability of treating the large low-grade gold-copper primary resource situated beneath the oxide cap. A trial pit was developed in 1996 allowing access to the ore for pilot-plant testwork. One of the options considered for the treatment of this ore, given the ore hardness, was HPGR. The primary ore is a combination of competent diorite and andesite with typical ball mill work indices of 14 to 17 kWh/t, rod mill work indices of 21 to 26 kWh/t, unconfined compressive strengths of 150 to 200 Mpa and Bond abrasion indices of 0.5 to 0.7.

At that stage, studded-roll technology was in its infancy and concerns about availability and costs of maintaining the wear surfaces of the rolls led to HPGR technology not being considered for the process at that time. However, it was also concluded that HPGR technology provided a power efficient comminution process for the ore (Parker et al. 2001).

HPGR pilot-plant trial. An agreement was reached with KHD to supply the same pilot-scale unit originally used at Kalgoorlie Consolidated Gold Mines in 1993. Krupp-Polysius was unable to provide a pilot unit in the time allowed. The HPGR pilot plant was commissioned during the early part of 1996. A total of 33,000 tonnes of ore for the trials were crushed in the Boddington supergene/basement plant and the product size was nominally 100% passing 35 mm. Two separate trials were undertaken, an open circuit trial to investigate operating parameters (Hart 1996a) followed by a closed circuit trial with a vibrating screen to determine machine availability and wear issues (Hart 1996b), and to provide material for down stream treatment and evaluation (Reese 1996). The pilot-plant circuit layout was similar to that used at KCGM with choke feeding of the HPGR and tramp metal protection. Operating parameters and particle sizing data from the open circuit trials are shown in Table 2.

TABLE 2

	Range
Open Circuit Trials	
Specific grinding force (N/mm^2)	3.5–6.5
Net specific power (kWh/t)	2.2–3.2
Throughput (tph)	35–58
HPGR Product Sizing	
% minus 3.35 mm	55–70
% minus 106 microns	17–25

TABLE 3

Operating Data	Trial 1	Trial 2	Trial 3
Tonnes treated	10,676	8,308	8,868
Screen aperture	12 mm	12 mm	7 mm
Recirculating load (%)	40	28	32
Net tonnes milled (t)	6,361	5,956	5,992
Availability (%)	85.0	90.5	89.7
Net average throughput (tph)	22.3	38.1	36.3
Net specific power (kWh/t)	4.0	3.1	2.1
Specific pressure (N/mm^2)	6.6	6.47	3.65
Product sizing (% - 3.35 mm)	81.2	63.6	56.3
Product sizing (% - 106 microns)	28.1	21.9	15.9

A reduction in HPGR roll speed from 0.91 m/s to 0.65 m/s had no effect on specific power consumption. Actual throughput dropped by 15% at the lower speed for a small increase in the production of fines. Specific grinding force had a moderate effect on product size distribution with a 4% increase in fines over the range tested. The “no load” gap settings were not found to influence machine or product operating conditions.

Following the open circuit test conditions were selected for closed circuit trials using 12-mm and 7-mm screen cloths on the vibrating screen. During the trial period 28,000 tonnes of ore were treated through the HPGR (new feed plus recycle from the screen) producing 18,000 tonnes of final product. Machine availability was 90% and this included significant downtime for temporary repair to the roll surface. Increasing the fines present in HPGR feed by recycling final product had a minor overall benefit in the production of fines. The recycle of 33% product increased throughput by the same amount and resulted in a 3% improvement in fines generation. Operating data from the trials are shown in Table 3.

Material wear rates were monitored closely during the trials. Cheek plate wear was significant at the start of the trial (lasting only 70 to 90 hours); however, movement of the plates away from the rolls (up to 10 mm) resolved this issue without an adverse effect on the integrity of products generating wear. Wear rates on both cheek plates and roll surfaces were considered the greatest risk leading to the decision to consider other process routes over HPGR. Dust management around the circuit was also highlighted as requiring attention in future studies.

TABLE 4

Operating Data	Trial 1	Trial 2	Trial 3	Crushed Ore
Tonnes milled	6,042	5,891	6,222	
Average feed rate (t/h)	71	68	76	63
Mill feed (F80 micron)	5,700	6,850	2,950	8,400
Grind size (P80 micron)	105	92	93	105
Operating ball mill Wi(kWh/t)	13.7	13.2	13.0	14.4

Ball-milling trials on HPGR product. The HPGR product were processed through the Boddington supergene /basement plant that had a ball mill and cyanide leaching circuit. The purpose of this was to determine the ball mill specific power and related calculated work indices as well as any improved leach performance compared to conventional crushing of the feed. During the ball trials routine both the ball feed conveyor and the ball mill cyclone overflow samples were collected for particle size analysis. The results from the ball mill trials are shown in Table 4.

Examination of continuous cyanide leach data on the ball mill cyclone overflows showed no statistical significant difference between the ore that was ball milled after HPGR treatment versus conventionally tertiary crushing.

HPGR TEST FACILITIES AND MODELLING

Test Facilities in Australia

HPGR test facilities within Australia are limited to those at CSIRO (Brisbane and Perth), Ammtec's recently commissioned facility in Perth and the HPGR located at the Independent Metallurgical Laboratory (IML) in Perth.

Laboratory Facilities

Laboratory facilities exist at CSIRO and IML in Australia. The CSIRO machine is a 250-mm diameter by 100-mm wide Krupp-Polysius machine fitted with smooth rolls. The "IML" machine is a Krupp-Polysius "Labwal" machine, 250-mm diameter by 100-mm wide fitted with studded rolls.

Pilot-Plant Facilities

For many years the only pilot-plant facility in Australia was located at CSIRO in Perth. The HPGR is an RPSR 2-80/25 KHD machine that is able to operate with roll speeds between 0.4 to 1.2 m/s. Treatment rates are typically between 20 and 70 t/h. The machine is usually used in a batch treatment mode. Oversize is removed by batch screening and recycled in the form of a "locked cycle" test to simulate plant operating conditions.

Ammtec has recently obtained a pilot HPGR unit supplied by Koeppern. The unit is 750 mm diameter by 220 mm wide and is fitted with a variable speed drive (to 1.55 m/s) and a Hexadur® wear surface allowing a maximum specific pressing force of 8.5 N/mm^2. This unit provides an alternative facility to the CSIRO facility for "pilot-scale" testwork and is capable of being relocated to site for more extensive and continuous evaluation.

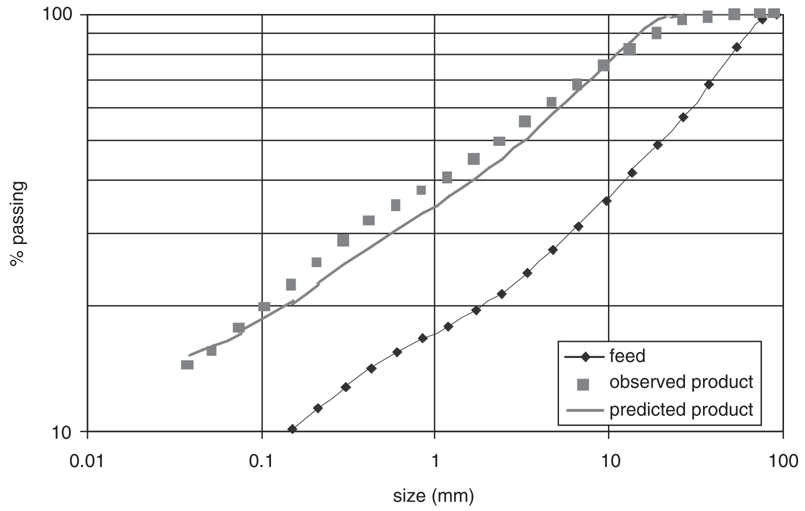

FIGURE 1 Observed versus predicted full-scale HPGR product size distribution

Modelling and Simulation

Modelling and simulation of HPGR performance is commercially available via the JKSimMet® software package. HPGR models based on general comminution principles have been developed over many years in AMIRA research projects that were/are supported by the mining industry. The JKSimMet® model caters for edge effect modelling and may be set up to model rock box by-pass.

Underlying the structure of the size reduction model are three assumptions about the inherent breakage mechanisms that occur in a HPGR (Morrell et al. 1997), namely:

1. If particles are bigger than a certain critical size they will be broken directly by the roll faces as would occur in a conventional rolls crusher.
2. Breakage at the edge of the rolls is different to that at the centre and conforms more to that experienced in a conventional roll crusher. This is the so-called "edge effect" which defines the proportion of relatively coarse particles usually seen in HPGR products.
3. At some point away from the edges of the rolls, and extending upwards from the area of minimum gap, is a compression zone where breakage conditions are those experienced in a compressed packed bed.

The model contains three breakage processes and one splitting process between the edge and compressed bed zones. For the breakage processes a conventional crushing model (Andersen 1988; Whiten 1972) is employed to describe the size reduction. The model has been validated under a range of conditions by calibrating it using laboratory-scale HPGR data then comparing its predictions of pilot- and full-scale performance with observed data. A typical result is given in Figure 1.

Recent data (Parker et al. 2001) has shown the HPGR performance is impacted by the porosity of the feed (i.e., bulk density/feed particle size). Other modelling issues

TABLE 5 Observed versus predicted wear on studded roll surface

Roll Speed, m/s	Stud Wear, mm	Predicted, hours	Observed, hours
0.91	3.6	455	443
0.65	1.4	234	298

such as screen efficiency (ability to deagglomerate flake) are both ore dependent, moisture dependent, machine dependent and circuit dependent.

Wear Model

A Brisbane-based company, SMCC, has developed an HPGR roll surface wear model. The approach relates the rate at which metal is removed from the roll surface as a function of its speed and surface area. This model uses data from laboratory-scale tests such as those carried out by Krupp-Polysius using their 100-mm diameter "Atwal" machine. The model fits a wear parameter to these data which is subsequently used in the model to predict roll life of operational machines. As a test of the model, data from the pilot programme undertaken at BGM in 1995 were used. Atwal wear tests were also carried out on a sample of feed ore. The model was therefore fitted to the Atwal data and then used to predict how long it would take for the studs to wear to the measured lengths during the various operating periods of the programme. The resultant predictions and the observed values are shown in Table 5.

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Index